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Geological Guidebook to the Paleoproterozoic East Bull Lake Intrusive Suite Plutons at East Bull Lake, Agnew Lake and River Valley, Ontario

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Geological Guidebook to the Paleoproterozoic East Bull Lake Intrusive Suite Plutons at East Bull Lake, Agnew Lake and River Valley, Ontario

by

R.M. Easton, L.S. Jobin-Bevans and R.S. James

2004

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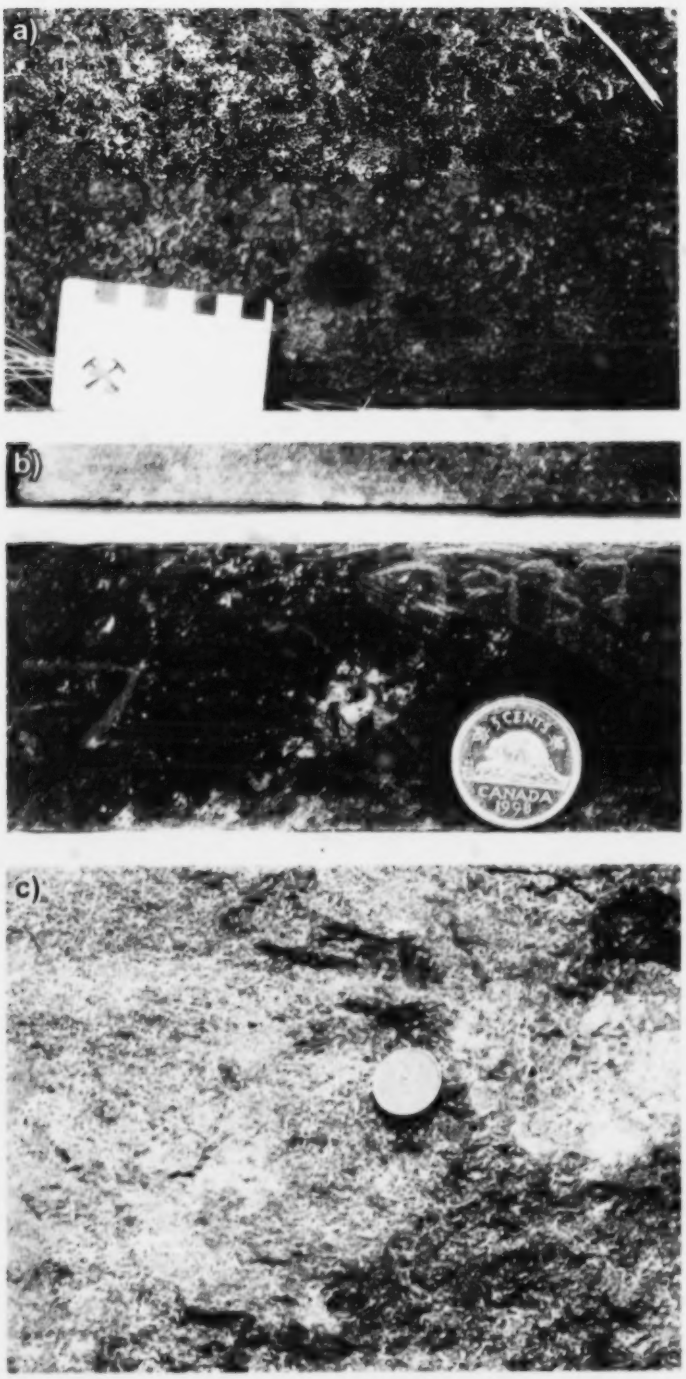
Abstract

Intrusions of the ~2480 million-year-old East Bull Lake intrusive suite occur as an east-northeast-trending belt along the boundary of the Archean Superior and the Proterozoic Southern provinces in Ontario, Canada. The East Bull Lake intrusive suite is part of a regional Paleoproterozoic, bimodal magmatic event resulting from a mantle-plume driven, intracontinental rifting event that formed a major basin, filled by sedimentary and igneous rocks of the Huronian Supergroup. Intrusions of similar age and composition in Finland and Wyoming were once contiguous with the East Bull Lake intrusive suite prior to tectonic dispersion during the Proterozoic.

Field and geochemical evidence indicates that the 3 largest intrusions (East Bull, Agnew, River Valley) crystallized from similar, low-Ti, high-Al, PGE-rich, tholeiitic parent magmas that originated in deeper, more mafic chambers. The primary magmas were likely second-stage melts derived from a sublithospheric depleted mantle source modified by Neoarchean subduction and accretion events. Petrologically, the intrusions reflect plagioclase-dominated fractional crystallization that generated a pronounced Fe-enrichment trend in the residual magmas. Olivine and orthopyroxene occur as cumulus phases in only the interpreted lower parts of the stratigraphy. Rhythmically and irregularly modally layered leucogabbronorite and gabbronorite make up much of the middle part of the stratigraphy. Ferrogabbro and ferrosyenite occur only in the uppermost Agnew Lake Intrusion. A marginal facies, comprising brecciated and, locally, thermally recrystallized and/or partially melted footwall rocks, is common and is testimony to a high-energy flow regime during initial emplacement. This marginal unit typically grades into a heterolithic, inclusion-rich gabbronorite with erratically distributed leucocratic to melanocratic autoliths and footwall xenoliths and eventually into a thick interval of undifferentiated, plagioclase-rich cumulates, locally with spectacular glomerocrystic textures.

Disseminated, bleb and interstitial magmatic chalcopyrite-pyrrhotite-pentlandite mineralization (1 to 5% sulphide minerals, up to 10 g/t Pt+Pd) occurs in autolith-rich gabbronorite breccia within 5 to 50 m of the contact of the intrusions. The mineralization is commonly spatially associated with pyroxenite cumulates and autoliths that are otherwise poorly represented in the stratigraphy. Vigorous convection and explosive breccia-producing emplacement of sulphide-saturated magma formed PGE-rich zones at the margins (sidewall or floor?). The magmatic sulphide zones are overprinted and enclosed by a broader envelope of metamorphic and/or hydrothermal sulphide mineralization of similar mineralogy (± pyrite) that extends into adjacent leucogabbronoritic to anorthositic units, and less so into the country rocks. The hydrothermally enriched zones contain 2 to 10% sulphide minerals with 1 to 10 g/t Pt+Pd, and represent the main exploration target. The high-grade zones are enclosed by broader, lower grade mineralization with Pt+Pd levels in the background range of 20 to 50 ppb.

Day long field excursions to each of the East Bull Lake, Agnew Lake, and River Valley intrusions are also included in this report. The combination of road accessible and walk-in stops is designed to illustrate important aspects of the geology, stratigraphy and mineralization found in each of the intrusions.



Frontispiece. Typical copper-nickel-PGE mineralization from the River Valley intrusion. **a**) Typical outcrop exposure of mineralized olivine gabbronorite from the River Valley intrusion in the vicinity of the Jackson's Flats occurrence. Note sulphide "burns" to the right of the 8.5 cm long scale card. **b**) Drill core from drill hole DL-14 in the Dana North area (Stop 9C, Day 3), showing the typical low tenor of sulphide and the presence of blue-grey quartz. A sample like this typically contains greater than 2 g/t of Pt and Pd mineralization. **c**) Close-up of mineralization from the Inclusion-Bearing unit at Dana South (Stop 9F, Day 3). All photographs courtesy of S. Jobin-Bevans.

Geological Guidebook to the Paleoproterozoic East Bull Lake Intrusive Suite Plutons at East Bull Lake, Agnew Lake and River Valley, Ontario

R.M. Easton[1], L.S. Jobin-Bevans[2] and R.S. James[3]
Ontario Geological Survey
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[1] Precambrian Geoscience Section, Ontario Geological Survey
Ministry of Northern Development and Mines, Sudbury, Ontario, Canada P3E 6B5

[2] Caracle Creek International Consulting Inc., Sudbury, Ontario, Canada P3E 2V7

[3] Department of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada P3E 2C6

Introduction

Since the summer of 1998, mafic intrusions of the East Bull Lake intrusive suite, specifically the East Bull Lake, Agnew Lake and the River Valley intrusions, have been the subject of ongoing copper-nickel-platinum group element (PGE) mineral exploration. This increased economic interest in these intrusions has led to renewed interest in the geology, stratigraphy and geochemistry of the East Bull Lake intrusive suite, as summarized by James et al. (2002a, 2002b) and Easton (2003).

After some 3 decades of study there are only a very few field trip guides to any of these intrusions. Peck et al. (2000) and Brisbin et al. (2001) produced guidebooks for the East Bull Lake Intrusion for PGE Exploration Workshops at Laurentian University in 2000 and 2001. A field guide for the Agnew Lake Intrusion has never been prepared. Hrominchuk and Jobin-Bevans (2000) prepared a guidebook for the River Valley intrusion to compliment the first PGE Exploration Workshop at Laurentian University in 2000. Earlier guides by Lumbers (1978) and Davidson (1986) included a few stops in the River Valley intrusion, but were prepared prior to detailed mapping of the intrusion.

The geology of the East Bull Lake suite intrusions is a significant topic in understanding the earliest evolution of the Southern Province in central Ontario. There are now numerous professional publications that describe and discuss the geology, geochemistry and mineral deposit potential of these intrusions (Table 1, and references in James et al. 2002a, 2002b). This integrated field guidebook to the East Bull Lake, Agnew Lake and River Valley intrusions is intended to compliment those studies. The field trip stops have been selected to show typical stratigraphic units in each intusion, as well as the geology of mineralized zones near the contacts of all 3 intrusions. The stops are also designed to compare and contrast the geological characteristics of the 3 major intrusions.

The field trip uses a combination of road accessible outcrops, as well as some stops that require some short traverses through the bush, generally utilizing trails of varied condition. Although most of the stops can be accessed using a two-wheel drive vehicle, use of a vehicle with high ground clearance and four-wheel drive capability is recommended for both the Agnew Lake and River Valley intrusion stops, especially in the spring and fall.

The structure of the guidebook is as follows: following the introduction, a brief overview of the East Bull Lake intrusive suite is provided. This is followed by descriptions of each one-day field trip to the East Bull Lake, Agnew Lake and River Valley intrusions. These descriptions include an overview of the geology, stratigraphy, geochemistry and mineralization in each intrusion, as well as a detailed road log and stop description. Day 1, the East Bull Lake Intrusion, was prepared mainly by R.S. James. Day 2, the Agnew Lake Intrusion, was prepared mainly by S. Jobin-Bevans and R.S. James. Day 3, the River Valley intrusion, was prepared mainly by R.M. Easton and S. Jobin-Bevans. The guidebook was compiled and edited by R.M. Easton.

SAFETY

For users of this guidebook, please bear in mind that some of the stops listed in this guidebook involve hiking in the bush. Therefore, standard bush safety practices should be followed by users of this guidebook. Such practices include travelling in pairs; advising others of your starting time and location and your expected return time; carrying sufficient water for the trip; being prepared for sudden changes in the weather; and carrying the appropriate emergency and safety gear. Most of the trip routes are on Crown land, but access is on or near private property for some routes. As in all such situations, please respect the property rights of others, so that future access for other geologists is not adversely affected.

ACKNOWLEDGEMENTS

The authors acknowledge the contributions of information kindly made available to them by Mustang Minerals Corporation with regard to access and information on the geology and mineralization of the East Bull Lake Intrusion. Pacific North West Capital Corporation and its partner Anglo American Platinum Corporation Limited are also thanked for similar information on the Agnew Lake and River Valley intrusions. Some of the material on the River Valley intrusion is related to work conducted as part of Ontario Geological Survey bedrock mapping projects PU99-007, 99-019, 01-009 and 02-008, as described in Easton (2003).

This guidebook was prepared initially for use with a field trip held in conjunction with the Geological Association of Canada–Mineralogical Association of Canada joint annual meeting in St. Catharines, May 12 to 14, 2004.

East Bull Lake Intrusive Suite

NOMENCLATURE

The term East Bull Lake intrusive suite was only recently introduced by Easton (1999), and is similar to the term, East Bull Lake suite, used by Vogel et al. (1999). Prior to 1991, rocks of this suite were generally only described as individual intrusions, or as gabbro-anorthosite bodies that were intrusive into the lower part of the Elliot Lake Group (e.g., Bennett, Dressler and Robertson 1991). Prevec et al. (1995) referred to rocks of the East Bull Lake intrusive suite as "trans-Huronian" intrusions. Keays et al. (1995) and Peck et al. (1995) grouped them as part of the Huronian–Nipissing Magmatic Province, Domain or Belt.

Nomenclature of individual intrusions within the East Bull Lake intrusive suite has been inconsistent over the years; however, James et al. (2002a) attempted to standardize the nomenclature for the intrusions within the suite, and to make this terminology consistent with the North American Stratigraphic Code (NACSN 1983). For example, the intrusion located west of Agnew Lake has been termed the Shakespeare–Dunlop intrusion, the Shakespeare–Dunlop gabbro-anorthosite intrusion, the Agnew Lake Intrusion and the Agnew intrusion, which was standardized in James et al. (2002a) as the Agnew Lake Intrusion. The standardization of nomenclature recommended by James et al. (2002a) is used herein, and is summarized in Table 1. Table 1 also includes the location of reference sections for the better-studied intrusions, details on contact relationships, and brief descriptions of the various intrusions.

Recent studies on the East Bull Lake intrusive suite have used a three-tiered classification scheme to describe the rocks of the suite (e.g., Chubb 1994; Vogel 1996; James et al. 2002a), which has been used in this report. The first-tier differentiates rock types based on colour index and variation in modal abundance of mafic minerals and plagioclase. The second-tier groups individual rock layers into mappable series, zones, subzones and units (Irvine 1982). It should be noted that units outlined by this second-tier classification are not formal stratigraphic units as defined by the North American Stratigraphic Code (NACSN 1983), although some units, in particular the zones, are roughly equivalent to lithodemic units. The third-tier is based on petrography or distinctive textures, but also uses the IUGS classification scheme for plutonic rocks (Le Maitre 1989) where primary mineralogy or whole-rock geochemistry is present. Most primary igneous mafic minerals are replaced by amphibole, chlorite and epidote group minerals (e.g., Kamineni et al. 1985; Kamineni 1986), which reflects regional metamorphism in East Bull Lake intrusive suite bodies in the Southern Province. Plagioclase may be unaltered or partially to completely

saussuritized. Rocks of the East Bull Lake intrusive suite within the Grenville Province can range from almost wholly unaltered to completely recrystallized to an upper amphibolite facies, amphibole-plagioclase assemblage (e.g., Easton and Hrominchuk 1999; Tettelaar 2000; Easton 2002). In either geological province where metamorphic alteration is pervasive, rock nomenclature is based on geochemically determined CIPW-normative mineralogy combined with petrographic data.

Unless otherwise stated, all UTM co-ordinates are in Zone 17, datum NAD 83. Unless otherwise noted, all analytical work in this report was completed by the Geoscience Laboratories, Geoservices Centre, Sudbury.

REGIONAL GEOLOGICAL SETTING

The Paleoproterozoic East Bull Lake intrusive suite (Easton 1999; James et al. 2002a) consists of several bodies of dominantly gabbronorite to gabbroic anorthosite that occur in both the Southern and Grenville provinces between Elliot Lake and the Ottawa River (Figure 1). The 3 largest bodies are the East Bull Lake and Agnew Lake intrusions (Southern Province) and the River Valley intrusion (Grenville Province) (*see* Table 1). All were emplaced between ~2491 and 2475 Ma (Table 2). Smaller bodies include the intrusions in Drury, Falconbridge, May, Street and Wisner townships (*see* Table 1, *see* Figure 1).

Most bodies of the East Bull Lake intrusive suite were emplaced into Archean rocks present in either the Superior or Grenville provinces. Table 3 summarizes the main geological events that have occurred in this part of the Canadian Shield during the Precambrian. The distribution of the bodies of the East Bull Lake intrusive suite approximates the base of the Huronian Supergroup in the Southern Province (*see* Figure 1). Contact relationships between rocks of the East Bull Lake intrusive suite and the Huronian Supergroup are either faulted or equivocal. Consequently, it is not known for certain if the East Bull Lake intrusive suite intruded the Huronian Supergroup, or was unconformably overlain by it, or both (e.g., Card 1978; McCrank et al. 1989; Peck, James and Chubb 1993).

Emplacement of the bodies of the East Bull Lake intrusive suite, subsequent eruption of volcanic rocks of the Huronian Supergroup, and formation of the depositional basin filled by Huronian Supergroup sediments is attributed by most authors (e.g., Card et al. 1972; Young 1983; Fahrig 1987; Hoffman 1989; Bennett, Dressler and Robertson 1991; Heaman 1997; Card and Poulsen 2000; Ernst and Buchan 2001) to an intracontinental rifting event resulting from a mantle-plume centred near Sudbury. A suite of igneous rocks (hereafter called the "rifting suite") records the initial trace of this plume-induced rifting event; from oldest to youngest, they include:

1. The East Bull Lake intrusive suite (~2490 to 2470 Ma).
2. Elliot Lake Group metavolcanic and minor plutonic rocks, for example, the Elsie Mountain, Stobie and Copper Cliff formations, May Township metavolcanic rocks, and minor synvolcanic mafic intrusions (~2490 to 2450 Ma). Metavolcanic rocks of the Elliot Lake Group constitute the lowermost of 4 stratigraphic groups in the Huronian Supergroup.
3. Matachewan (2473 Ma) and Hearst (2446 Ma) mafic dike swarms (Heaman 1997).
4. Granitic intrusions within the Elliot Lake Group and the Superior Province (~2385 to 2460 Ma), including the Creighton and Murray plutons and the Street Township granitic plutons that may be coeval with Elliot Lake Group felsic volcanism.

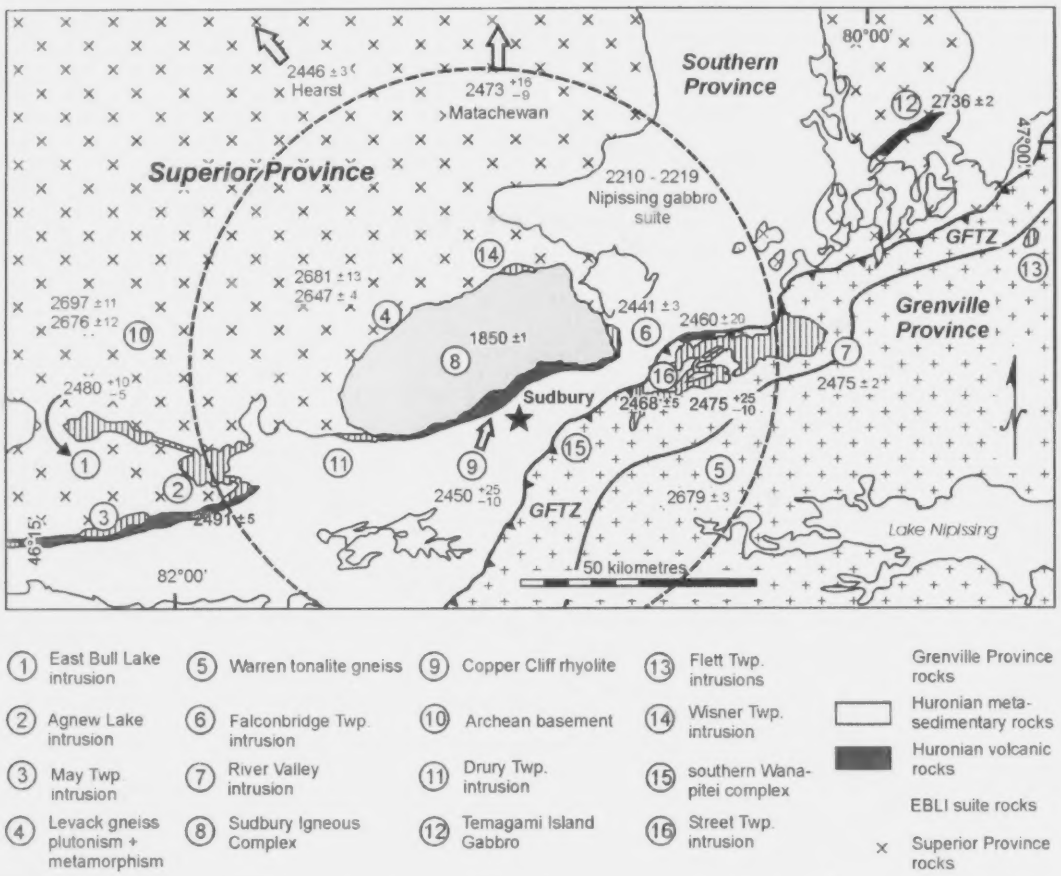

Figure 1. Distribution of U-Pb zircon ages from Neoarchean and Paleoproterozoic rocks in the Sudbury area, as well as the distribution of East Bull Lake intrusive suite bodies. Dashed circle indicates 125 km radius from a point central to the Sudbury Structure; most intrusions lie within this radius. Sources used: 1, 2, 8, 9) Krogh, Davis and Corfu 1984; 4) Wodicka and Card 1995; Krogh, Davis and Corfu 1984; 5) Chen, Krogh and Lumbers 1995; 6 and 10) Prevec 1993; 7) Heaman in Easton, Davidson and Murphy 1999; below and above circle 16, Corfu and Easton (2000). Age of Hearst and Matachewan dikes from Heaman (1997). Abbreviations: GFTZ = Grenville Front tectonic zone; EBLI = East Bull Lake intrusive suite.

Current geochronological data suggests 2 main pulses in magmatism.

1. A predominantly mafic pulse at ~2475 Ma, represented by the East Bull Lake intrusive suite, Matachewan dikes, and the mafic part of the Elliot Lake Group.
2. A felsic-dominated pulse at ~2450 Ma, represented by felsic metavolcanic rocks of the Elliot Lake Group, related granitic intrusions, and Hearst dikes.

The rifting event produced an east-trending, southward-deepening basin that likely resulted in formation of oceanic crust (e.g., Card et al. 1972; Young 1983; Fahrig 1987; Hoffman 1989; Bennett, Dressler and Robertson 1991). The geometry of the Matachewan and Hearst dikes and their distribution with respect to the metavolcanic rocks of the Elliot Lake Group is consistent with the north-northwest trend of the dikes reflecting the orientation of a failed arm of the rift (e.g., Fahrig 1987; Ernst and Buchan 2001). If this geometry is correct, then the east-trending East Bull Lake intrusive suite bodies not only occur along the continent-side of the rift basin, but also within a 125 km radius of a plume centered on Sudbury (*see* Figure 1). At present, it is uncertain if the rocks of East Bull Lake intrusive suite occur directly along a cryptic structure, or structures, related to this rift basin, or if the present distribution of the bodies reflects some other emplacement mechanism (James et al. 2002a).

Table 1. Summary of stratigraphic, mineralogical and geochemical data for the East Bull Lake intrusive suite (*modified from* James et al. 2002a; Easton 2003).

Intrusion	Size (km^2)	Dominant Rock Types	Metamorphic Grade	Geochemisty	Primary Mineral Chemistry	Contact relationships	Stratigraphic Thickness	Location of Reference Sections, UTM Zone 17, NAD 83	References
Southern Province hosted intrusions									
Agnew Lake *or* Shakespeare –Dunlop	50	Leucogabbronorite gabbronorite, olivine gabbronorite.	Upper greenschist to lower amphibolite	n = ~100 major and trace element analyses, REE and isotope data also available	Plag = An_{2-79}	Ramsey-Algoma granitoid complex rocks in footwall, diking and brecciation in footwall at contacts, to east, possible unconformable contact with Huronian Sgp. metasedimentary rocks.	at least 1000m, as much as 2100 m in some interpretations	Not defined	Vogel 1996; Vogel, James and Keays 1998; Vogel et al. 1999
Drury Twp. *or* Worthington	8-10	Leucogabbro, gabbro.	Shock metamorphosed, locally upper greenschist	n = ~5 major and trace element analyses, REE and isotope data also available	No data	Contacts typically zones rich in Sudbury breccia. Intrusion in contact aureole of the Sudbury Igneous Complex.	Unknown	Not defined	Brons 1984; Prevec 1993
East Bull Lake, *includes* outliers at Splake and Tee Lakes	43	Leucogabbronorite gabbronorite, olivine gabbronorite.	Lower to upper greenschist	n = ~200 major and trace element analyses, REE and isotope data also available	Plag = An_{60-80} Rhythmically layered zone: ol = Fo_{59-65}, opx = $En_{64-66}Fs_{30-32}Wo_4$, cpx = $En_{41-45}Fs_{15-16}Wo_{39-44}$ Olivine gabbronorite zone: ol = Fo_{65-74}, opx = $En_{67-70}Fs_{26-29}Wo_4$, cpx = $En_{41-43}Fs_{14-15}Wo_{43-44}$	Parisien Lake syenite, Whiskey Lake greenstone belt, Ramsey-Algoma granitoid complex rock, diking and brecciation in footwall at contacts, possible unconformable contact with Huronian Supergroup metasediments to the north.	~850 m	Not defined.	Born 1979; James and Born 1985; McCrank et al. 1989; Peck, James and Chubb 1993; Peck et al. 1995; Prevec 1993, Vogel , James and Keays 1998
Falconbridge Twp. *or* Norduna	1-2	Leucogabbronorite gabbronorite.	Shock metamorphosed, upper greenschist	n = 8 major and trace element analyses, REE and isotope data also available	Plag = An_{60-76}	Contacts typically zones rich in Sudbury breccia. Intrusion in contact aureole of the Sudbury Igneous Complex.	Unknown	Not defined	DeGagne 1982, Prevec 1993
May Twp. *or* Salmay Lake	15	Leucogabbro, gabbro, melanogabbro.	Lower to upper greenschist	n = ~15 major and trace element analyses, REE and isotope data also available	No data	Melanogabbro better preserved than leucocratic rocks.	Unknown	Not defined	Cape 1973, Robertson 1976, Prevec 1993
Wisner Twp.	~5	Leucogabbronorite	Shock metamorphosed, upper greenschist?		No data	Unknown	Unknown	Not defined	Vogel, James and Keays 1998

Table 1. continued

Intrusion	Size (km^2)	Dominant Rock Types	Metamorphic Grade	Geochemisty	Primary Mineral Chemistry	Contact relationships	Stratigraphic Thickness	Location of Reference Sections, UTM Zone 17, NAD 83	References
Grenville Province hosted intrusions									
River Valley	~100	Leucogabbronorite gabbronorite, olivine gabbronorite.	Greenschist to upper amphibolite, with some areas of primary mineralogy preserved, mainly in Dana Township.	n = ~70 major and trace element analyses, REE data also available	Marginal zone: Plag = An_{79} (core); An_{68}, (intercumulate) Olivine gabbronorite zone: ol = Fo_{74} plag = An_{70-75} opx = En_{60-80}	***Primary Contacts: Dana Twp.:*** Sharp contact with paragneiss or alkali feldspar granite, no dikes in footwall, marginal zone contains footwall xenoliths. Fault contacts with Huronian Sgp. metasedimentary and metavolcanic rocks, equivocal contact with Nipissing gabbro. ***Crerar Twp:*** Sharp contact with alkali feldspar granite, alteration of granite in footwall, fine-grained phase at contact, no dikes in footwall, marginal zone contains footwall xenoliths. Hosted by Crerar gneiss association.	~1000 m	Marginal zone: 555310E, 5172625N; 556610E, 5174225N to 556510E, 5171225N; 558760E, 5167825N to 558510E, 5167475N. Olivine Gabbronorite zone: 559260E, 516825N; 563260E, 5166225N; 560410E, 5167825N. Gabbronorite zone: 558510E, 5165575N	Easton and Hrominchuk 1999; Hrominchuk 1999, 2000; Easton 2003
Loughrin Lake	~25	Gneissic leucogabbronorite, gabbronorite, associated orthopyroxene hornblendite.	Upper amphibolite	n = 12 major and trace element analyses, REE data also available	No data	North contact mainly tectonic. South contact sharp, with scattered orthopyroxene hornblendite bodies. Hosted by Street gneiss association.	~500 to 1000m	Not defined	Easton 2003
Contact	~5	Gneissic, leucogabbronorite, gabbronorite, associated orthopyroxene hornblendite.	Upper amphibolite	No data	No data	North contact locally cut by Geon 24 to 23 felsic intrusions. South contact sharp, with scattered orthopyroxene hornblendite bodies. Hosted by Street and Crerar gneiss association.	less than 500 m	Not defined	Easton 2003
Third Concession	~5	Gneissic leucogabbronorite, gabbronorite, associated orthopyroxene hornblendite.	Upper amphibolite	n = 1 major and trace element and REE analyses	No data	Same as Contact intrusion. Both contacts locally intrude migmatitic garnet amphibolite. Hosted by Street gneiss association.	~500 m	Not defined	Easton 2003

Table 1. continued

Intrusion	Size (km^2)	Dominant Rock Types	Metamorphic Grade	Geochemisty	Primary Mineral Chemistry	Contact relationships	Stratigraphic Thickness	Location of Reference Sections, UTM Zone 17, NAD 83	References
Street metagabbro	~5	Leucogabbronorite gabbronorite, norite, associated orthopyroxene hornblendite	Upper amphibolite	n = 25 major, trace element and REE analyses	Coronitic orthopyroxene present	Basal contact intrudes migmatitic garnet amphibolite, ~2475 Ma granites contain fragments of intrusion. Hosted by Street gneiss association.	less than 500 m	530510E, 5155225 to 5155725N	Easton 1999, 2003; Easton and Murphy 2002
Red Deer Lake	~10	Gneissic leucogabbro, gabbro, norite.	Upper amphibolite	n = 1 major element analysis	No data	Unknown	Unknown	Not defined	Lumbers 1975
southern Wanapitei complex	~5	Gneissic leucogabbronorite, gabbronorite.	Upper amphibolite	n = 8 major element analyses	Coronitic olivine present	Unknown	Unknown	Not defined	Rousell and Trevisiol 1988

Table 2. Summary of geochronology on rocks of the East Bull Lake intrusive suite (*from* Easton 2003).

Intrusion	Age (in Ma)	Method	Reference	Comment
Absolute Ages				
Agnew Lake	2491±5	U/Pb zircon	Krogh, Davis and Corfu (1984)	from alkali feldspar granite that may not be part of the intrusion.
East Bull Lake	$2480^{+10}/_{-5}$	U/Pb baddeleyite and zircon	Krogh, Davis and Corfu (1984)	from olivine gabbronorite zone, few grain, hence high error.
	2472±76	Nd/Sm whole-rock and mineral	McCrank et al. (1989)	from olivine gabbronorite zone.
	1859±5	Ar/Ar hornblende	Kamineni (1986)	no details on location.
	1725±18	K/Ar whole rock	McCrank et al. (1989)	from olivine gabbronorite zone.
	1155±14	K/Ar whole rock	McCrank et al. (1989)	from olivine gabbronorite zone.
Drury Twp.	1855±10	U/Pb zircon	Prevec (1993)	shocked zircons, dates Sudbury event.
Falconbridge Twp.	2441±3	U/Pb zircon	Prevec (1993)	
	~1850	U/Pb zircon	Prevec (1993)	lower intercept, dates Sudbury event.
River Valley	$2475^{+2}/_{-1}$	U/Pb baddeleyite and zircon	Heaman, unpublished *in* Easton, Davidson and Murphy (1999)	from layered gabbronorite zone, either in Erana or Dana quarries, north of Sturgeon River.
	2562±165	Pb/Pb whole-rock	Ashwal and Wooden (1989)	n=6, igneous textured samples only.
	2377±68 2165±130	Nd/Sm whole-rock and mineral	Ashwal and Wooden (1989)	n=4, igneous textured samples only, second age is resetting event.
	2185±105, 1960±100	Rb/Sr whole-rock	Ashwal and Wooden (1989)	n=4, second age is resetting event.
Street Twp.	2468±5	U/Pb zircon	Corfu and Easton (2000)	age from orthopyroxene hornblendite body thought to be genetically related to East Bull Lake intrusive suite.
Relative Ages				
River Valley	>2446±3	U/Pb baddeleyite and zircon	Heaman (1997)	Dikes of the Matachewan dike swarm cut the River Valley intrusion.
	>2460±20, $2475^{+25}/_{-10}$	U/Pb zircon	Corfu and Easton (2000), Easton and Hrominchuk (1999)	Felsic dikes likely related to felsic intrusions coeval with Huronian Stobie Formation cut the River Valley intrusion.

Table 3. Timing of major geological events and summary of age constraints on the main rock units present in the study area (*from* Easton 2003).

Event and/or Map Unit	Age Constraint (in Ma)	Comment and/or Source
Grenville dike swarm	586±4	Kamo, Krogh and Kumarapeli (1995)
Pegmatite vein emplacement	989±2	Corfu and Easton (2000)
Age of peak metamorphism in the hanging wall of the Grenville Front tectonic zone	1000 to 990	Corfu and Easton (2000)
Age of peak Grenvillian metamorphism in Crerar and Dana townships	1040 and 1030	this study; see also Carr et al. (2000)
Sudbury dike swarm	1238±4	emplaced in or along northwest-trending faults in the Southern Province. Deformed and metamorphosed within the Grenville Province. Krogh et al. (1987).
Killarney magmatic belt second-stage magmatism, coincident with magmatism in the Eastern Granite Rhyolite Province and in the Central Gneiss Belt	1471±3	van Breemen and Davidson (1988)
Regional albitization metasomatic event	1701±4	U/Pb monazite, Schandl, Gorton and Davis (1994); fluid focussed along northwest-trending faults
Killarney magmatic belt volcanism and high-level plutonism	1740, 1747±3, 1749±12	van Breemen and Davidson (1988); Sullivan and Davidson (1993); Davidson and van Breemen (1994)
Northwest-trending regional faults	Pre-1700, post-1850	Faults cut Sudbury Structure
Penokean Orogeny (folding and metamorphism of Huronian Supergroup rocks)	~1835	Peak metamorphism. Holm et al. (2001).
Impact event and formation of Sudbury breccia	1850±1	Krogh, Davis and Corfu (1984)
Thrust faulting	post-F_2 pre-regional faulting	Sudbury breccia localized along these faults, suggesting they are pre-Sudbury Structure
F_2 folding	post-2200, pre-1700, pre 1850?	Pre-regional faulting, Nipissing sills folded, relationship to Sudbury Structure uncertain
F_1 folding	Pre-2200	Nipissing sills in Street Township appear unaffected by this folding
Emplacement of Nipissing gabbro sills	2219±4 to 2210±4	Corfu and Andrews (1986); Noble and Lightfoot (1992)
Huronian sedimentation	>2220 but <2460	
Huronian felsic volcanism and related plutonic rocks	~2477 to 2375 (2450±25, 2460±20, 2477±9, 2415±5, 2376±2)	Krogh, Davis and Corfu (1984), Corfu and Easton (2000), Krogh, Kamo and Bohor (1996), Smith (2002)
Emplacement of East Bull Lake intrusive suite rocks	2475±2 see also Table 2	Heaman (geochronologist, University of Alberta, personal communication, 1999)
Emplacement of orthopyroxene hornblendite bodies	2468±5	Corfu and Easton (2000)
Emplacement of alkali feldspar granite bodies in Crerar and Dana townships	2640	Bodies intrude Crerar and Pardo gneiss, this study
High-grade Archean metamorphism and migmatization	2647±4	Krogh, Davis and Corfu (1984); Wodicka and Card (1995)
Emplacement of megacrystic granodiorite bodies in Crerar gneiss association	2660	this study
Emplacement ages of Archean units in the Sudbury area	2711±7 to 2642±1	Krogh, Davis and Corfu (1984); Wodicka and Card (1995); Chen, Krogh and Lumbers (1995); Meldrum et al. (1997)

Within the Southern Province, rocks of the East Bull Lake intrusive suite are affected by folding and upper greenschist to lower amphibolite facies metamorphism associated with the Penokean Orogeny, likely around 1835 Ma (Holm et al. 2001; *see also* Table 3). Within the Grenville Province, rocks of the East Bull Lake intrusive suite may have been locally affected by metamorphism and deformation at ~1700 Ma and ~1450 Ma, in addition to the main pulse of Grenville orogenesis at ~1070 to 1040 Ma (Corfu and Easton 2000).

OVERVIEW OF EAST BULL LAKE INTRUSIVE SUITE

Table 1 lists all known major members of the East Bull Lake intrusive suite along with notable features common to all and a listing of all studies performed to date. The distribution of the bodies is illustrated in Figure 1. Table 2 summarizes the geochronology of the intrusive suite. The 3 largest intrusions are the East Bull Lake, Agnew Lake, and River Valley intrusions, all of which have been mapped in the last 25 years at either 1:10 000 or 1:20 000 scale in whole or in part (Born 1979; Kamineni et al. 1984; Chubb 1994; Peck et al. 1995; Vogel 1996; Easton and Hrominchuk 2001a, 2001b), with accompanying petrological, geochemical or economic studies (James and Born 1985; McCrank et al. 1989; Chubb 1994; Peck, James and Chubb 1993; Peck et al.1995; Vogel 1996; Vogel, James and Keays 1998; Vogel et al. 1998, 1999; Easton and Hrominchuk 1999; Hrominchuk 1999, 2000; Peck et al. 2001; James et al. 2002a, 2002b).

The preserved size of the intrusions varies from 1 to ~100 km^2 (Table 1). The most completely preserved body is the Agnew Lake Intrusion with approximately 2 km of stratigraphic section; both the East Bull Lake Intrusion and River Valley intrusion contain roughly 1 km of section. The East Bull Lake, Agnew Lake and River Valley intrusions are sporadically layered at centimetre- to decametre-scale throughout their stratigraphy.

Leucogabbronorite and gabbronorite are the dominant rock types in the lower and middle parts of most bodies of the East Bull Lake intrusive suite. Olivine gabbronorites and leucogabbronorites are common in the Main Series of the East Bull Lake intrusion and the Lower Series of the Agnew Lake Intrusion. Melagabbronorites and troctolites are common in the lower parts of the River Valley intrusion. Ferrogabbros, ferrosyenites and alkali granites form the top 150 m of the Agnew Lake Intrusion. The significant volume of melanocratic norites and troctolites recognized in the River Valley Intrusion is not present in those intrusions west of the Grenville Front, and may indicate that the former represent a deeper part of the stratigraphy of this intrusive suite. The crystallization order of primocryst phases in most of the intrusions is plagioclase, olivine, orthopyroxene, clinopyroxene and titanomagnetite. The attitude of metre-scale phase layering and stratigraphic units in the East Bull Lake and Agnew Lake intrusions suggest that they represent lopoliths joined by dike-like units (James et al. 2002a). Original geometry of the bodies present in the Grenville Province cannot be reliably ascertained, although the northeast part of the River Valley intrusion appears to be a shallowly-dipping (10 to 30°) sheet.

Without exception, breccias containing footwall and mafic cognate xenoliths in a gabbronorite matrix occur at the base of all intrusions, where the footwall contact is preserved. The thickness and abundance of these breccia units varies considerably. Also near the contact, footwall breccias and zones of extensive footwall dikes may be present. Disseminated chalcopyrite and pyrrhotite, typically in modal amounts from 0.5 to 2.0%, occur in the matrix of the marginal and brecciated rocks. This sulphide mineralization commonly contains between 1 and 5 g/t of combined Pt+Pd+Au, and is the focus for current mineral exploration (James et al. 2002a, 2002b).

DEPTH AND MECHANISM OF EMPLACEMENT

Researchers studying East Bull Lake suite intrusions in the Southern Province have suggested shallow depths of emplacement (<8 km), possibly at the contact between the Archean basement and overlying supracrustal rocks of the Huronian Supergroup and its precursors (e.g., Card 1978; Peck et al. 1995; Vogel et al. 1998, 1999). In contrast, researchers studying the River Valley intrusion have favoured moderate to deeper depths of emplacement (8 to 12 km), either at the boundary between Archean plutonic rocks and greenstone belts or at the boundary between gneisses and a plutonic rock-dominated mid-crustal layer (e.g., Easton 2000; J.L. Hrominchuk, personal communication, 2000). Easton (2002) went further, suggesting that several depths of emplacement are recorded within the East Bull Lake intrusive suite, based on the fact that the intrusive bodies display subtly different features depending on which country rock gneiss association they are in contact with.

Two models have been proposed with respect to the emplacement mechanism of the East Bull Lake intrusive suite; both are discussed in James et al. (2002a), and are summarized here. The first model has been proposed specifically for the area extending from Elliot Lake to Sudbury. Based on geologic reconstruction and "unfolding" of the effects of Penokean deformation on the East Bull Lake and the Agnew Lake intrusions, and their similar stratigraphy, it has been proposed that the middle and upper parts of both these intrusions were part of an extensive, subhorizontal sheet. This sheet may have been approximately 2 km thick, representing the upper 75% of a lopolith that had horizontal dimensions of 30 to 50 km in a northerly direction and greater than 100 km in an easterly direction (James et al. 2002a; Vogel et al. 1999). In this model the lower and mineralized sections of the intrusions occupied rift fault-related structures or embayments that controlled magma intrusion, replenishment, and mineralization, and thus, may not have been as widespread as the main mass of the lopolith. Furthermore, the mineralized zones would not have been connected. This model has been expanded to include the possibility that the East Bull Lake, Agnew Lake, and River Valley intrusions, as well as the intervening smaller intrusions (*see* Figure 1, Table 1), are the remnants of one large interconnected Great Dike-like lopolith that can be traced for at least 300 km across central Ontario (*see* Figure 1) (James et al. 2002a). If so, then small size is not a concern in terms of modelling the potential size of mineralized sections, and the area of potential interest for exploration is much larger.

The second model proposes that the East Bull Lake intrusive suite was emplaced as a group of smaller, separate bodies, rather than as one or two large, now dismembered, sill complexes (James et al. 2002a). One consequence of this model is that the various bodies could have been emplaced at different crustal levels. This model would also provide an explanation for the differences in stratigraphy between the various intrusions, as not every intrusion would differentiate to the same degree. Finally, an important implication of this model is that mineralization style and grade will vary between intrusions.

MAGMA COMPOSITION AND ITS RELATIONSHIP TO MINERALIZATION

Detailed studies (Peck et al. 1995, 2001; Vogel et al., 1999; James et al. 2002a, 2002b) demonstrate that the magma(s) that formed the East Bull Lake and the Agnew Lake intrusions were high-Al, low-Ti (Al_2O_3 ~17.5 wt %; TiO_2 ~0.5 wt %) tholeiites. In these 2 intrusions, the main fractionation trend formed by leucogabbronorite and norites is interrupted by emplacement of more primitive (less fractionated), olivine-rich rocks (the Olivine Gabbronorite zones) which form a distinctive geochemical pattern not easily attributed to the same magma source.

For the River Valley intrusion, at least north of the Sturgeon River, its stratigraphy, including the Olivine Gabbronorite, Gabbronorite and Leucogabbronorite zones, could be attributed to a magnesian variant (8 to 10 % MgO) of the high-Al, low-Ti, tholeiite (James et al. 2002a). Such magma would have olivine followed by plagioclase on the liquidus, which satisfies the petrographic data for these rocks. The magma giving rise to the sporadically mineralized orthopyroxene-phyric norite and gabbronorite that is the main component of the Marginal Zone of the River Valley intrusion is part of an earlier magmatic sequence: its pyroxene-phyric, olivine-absent character and disseminated PGE mineralization distinguish it from norites and gabbronorites higher in the stratigraphy (James et al. 2002a).

The magmatic evolution of River Valley intrusion, however, is not as well constrained as it is for the East Bull Lake and Agnew Lake intrusions. As noted by Hrominchuk in James et al. (2002a), a unit of massive, medium-grained, orthopyroxene-phyric norite with a boninitic composition (MgO ~11.5 wt %, Al_2O_3 ~13.5 wt. %, SiO_2 ~51.5 wt %), located near the southeast margin of the River Valley intrusion, could represent the parent magma of the intrusion. Furthermore, Hrominchuk argued that the Olivine Gabbronorite, Gabbronorite and Leucogabbronorite zones were derived from this boninitic parental magma by a combination of fractional crystallization and mixing of variably fractionated magma batches within the magma chamber. With the available analytical data, it is equally plausible, however, that the Olivine Gabbronorite, Gabbronorite and Leucogabbronorite zones of the River Valley intrusion formed from a high-Al, low-Ti magma similar to that which produced the East Bull Lake and the Agnew Lake intrusions. The boninitic magma may have only been injected near the base of the intrusion to form the Marginal and Inclusion and/or Fragment-bearing zones (James et al. 2002a).

An argument against a boninitic parental magma is that such magmas are currently found only in ocean island arc settings (e.g., Bonin islands, Japan, Papau New Guinea), unlike the inferred continental-rift plume-setting for the East Bull Lake intrusive suite. Nonetheless, boninites are thought to form from a relatively high degree of partial melting of previously melted metasomatized lithospheric mantle (Hamlyn et al. 1985). Metasomatism is generally thought to occur from fluids derived from dehydration of a subducted slab of oceanic crust (Hickey and Frey 1982) and can produce light rare earth element (LREE) enrichment in the resulting melt.

Alternatively, crustal contamination of a second-stage mantle melt can produce LREE enrichment in an otherwise primitive melt (Vogel et al. 1999). Vogel et al. (1999) found crustal contamination to be an unlikely mechanism for the uniformly elevated LREE in the Agnew Lake Intrusion, and suggested that the parent magma must have come from a partial mantle melt enriched by LREE-rich fluids. In the case of the River Valley intrusion, the LREE and trace element patterns are much less uniform and contamination is an important process, especially in the Marginal and Inclusion and/or Fragment-bearing zones (Hrominchuk 2000), which is one reason to favour a boninitic parental magma (James et al. 2002a). Regardless, both the proposed high-Al, low-Ti and boninitic parental magmas are second-stage, mantle-derived magmas as described by (Hamlyn and Keays 1986).

Hamlyn and Keays (1986) argued that second-stage magmas are critical to the formation of PGE deposits, a view also favoured in James et al. (2002a, 2002b). These fertile magmas arise from previously depleted mantle, typically in areas underlying Precambrian cratons or island arcs. Both the interpreted high-Al and boninitic parental magmas of the East Bull Lake intrusive suite are PGE fertile (Pt+Pd ~20 to 50 ppb) and sulphur-poor (~100 to 200 ppm), and together with their continental rift-margin tectonic setting, are good examples of second-stage magmas. Their low sulphur-content likely reflects prior extraction of MORB-type basalt liquids from the mantle, which removed most of the mantle sulphide phase, but left a small amount of a PGE-rich residual sulphide phase (Keays 1995). Pd and Se data from barren cumulates and possible feeder dikes from the East Bull Lake Intrusion (Peck et al. 2001) illustrates the PGE-rich nature of the parental magmas compared to first stage (MORB-type) magmas derived from fertile mantle, which have significantly higher S(Se) and lower PGE/S(Se) ratios.

In terms of crust-mantle scale processes, James et al. (2002a) suggested that fractional crystallization of a mantle-derived, second-stage magma in the lower to middle crust generated PGE-enriched, sulphur-undersaturated leuconorite or norite magmas in the upper part of a zoned ultramafic to mafic magma chamber. During ascent and intrusion into the upper crust, this buoyant residual magma (parent to much of the marginal parts of the East Bull Lake and Agnew Lake intrusions) became sulphur-saturated, and apparently escaped from the more primitive subchamber without the loss of the sulphide phase. In this model, rocks of the more primitive Olivine Gabbronorite zone in the East Bull Lake and Agnew Lake intrusions represent influxes of magma from the more mafic parts of the same magmatic system. They should be relatively barren in PGE, except where mixing with fractionated liquids from the high-Al magmas may have generated reef-type deposits. Similar layered olivine-rich rocks in the River Valley intrusion appear to be part of a fractionating system that forms norites and leucogabbros in the upper part of this body (James et al. 2002a).

Detailed studies on PGE mineralization have been done only on the East Bull Lake Intrusion. Many fine-grained gabbros in the Marginal Series and feeder-type plagioclase-phyric dikes in the footwall, have 20 to 100 ppb Pt+Pd (Pd/Pt = 2:1 to 1:1) and contain small (<1%) amounts of fine-grained disseminated sulphide minerals (pyrite ± pyrrhotite ± chalcopyrite). These PGE and sulphide contents are interpreted as evidence that early magma pulses were sulphur-saturated when they entered the magma chamber (James et al. 2002a). The PGE values in these rocks far exceed those expected for basaltic liquids, even those derived from depleted mantle sources (Hamlyn and Keays 1986; Keays 1995), which is further evidence for sulphur saturation. Vigorous convection within the magma chamber, as evidenced by the Inclusion-bearing and Anorthosite zones at the East Bull Lake Intrusion, produced high silicate/sulphide liquid mass ratios that allowed growing sulphide liquid droplets to attain the observed high PGE contents (1 to 10 g/t) (James et al. 2002a).

ORTHOPYROXENE HORNBLENDITE BODIES

Bodies of orthopyroxene hornblendite consist of orthopyroxene (bronzite) phenocrysts, ranging from 0.5 to 5 cm in length, hosted in a fine-grained amphibole-plagioclase matrix (Photo 1). These bodies occur throughout Awrey, Dryden, Henry, Loughrin and Street townships (Easton 1998, 1999, 2002, 2003; Easton and Murphy 2002; Davidson 1998). Large glacial erratics of orthopyroxene hornblendite, some up to 6 m across, are common in Henry, Loughrin and Street townships. The erratics are generally found within several hundred metres of observed bodies in outcrop, or in areas where bodies may be hidden beneath overburden. In most of these aforementioned townships, the orthopyroxene hornblendite bodies are found in close proximity to mafic intrusive rocks of the East Bull Lake intrusive suite. Zircon from an orthopyroxene hornblendite body in Street Township has been dated at 2468±5 Ma (Corfu and Easton 2000), similar in age to other intrusive rocks of the East Bull Lake intrusive suite (James et al. 2002a).

Even though some orthopyroxene hornblendite bodies occur within 100 m of the Grenville Front (Easton and Murphy 2002; Hubbard 1998), equivalent rocks to these bodies have not been reported in conjunction with East Bull Lake intrusive suite bodies located within the Southern Province. No orthopyroxene hornblendite bodies have been found in association with the River Valley intrusion, although some ultramafic layers present within the River Valley intrusion in Crerar Township are chemically similar to rocks of the orthopyroxene hornblendite suite, even though they are texturally and mineralogically distinct. Easton (2002) suggested that the orthopyroxene hornblendite bodies are restricted to country rocks of the Street gneiss association, although some bodies do occur in association with other East Bull Lake intrusive suite rocks along the boundary between the Street and Crerar gneiss associations. This would explain the absence of these rocks in the Southern Province and in association with the River Valley intrusion, as well as their abundance in Awrey, Dryden, Henry, Loughrin and Street townships, all of which are underlain by rocks of the Street gneiss association.

Photo 1. Orthopyroxene phenocrysts in matrix-rich orthopyroxene hornblendite in Henry Township. Hammer handle is 30 cm long. UTM 547314E 5158815N.

Easton and Murphy (2002) suggested that these bodies exhibited only 2 types of contact relationships; however, work by Easton (2003) suggests that there might be 4 types of contact relationships. These contact types are summarized below:

1. The first type occur near sharp, possibly modified igneous contacts between metagabbroic and metaleucogabbroic rocks of the East Bull Lake intrusive suite and their host gneisses (Street gneiss association). Bodies of this type appear to have been emplaced into pre-existing embayments along the metagabbro-gneiss contact. All of the Street Township bodies are of this type.
2. The second type occurs within deformation zones characterized by flattened gneissic rocks (e.g., the body exposed on the south side of Highway 17 in Awrey Township, Stop 1, Day 3).
3. Some bodies in Loughrin Township, show a linear distribution and may represent boudinaged dikes. It is possible that types 2 and 3 are related, with type 2 representing a more deformed version of type 3.
4. Many of the larger bodies found in Henry and Loughrin townships, are not clearly associated with the contact of any of the East Bull Lake intrusive suite bodies. Some are located over 1 km from the contact.

The field term for these rocks, orthopyroxene hornblendite, is based on the dominant mineral phases observed in hand sample. Some of the better-preserved bodies contain relict olivine grains. Mesonorm calculations suggest a metamorphic mineralogy dominated by pyroxene and amphibole consistent with the observed mineralogy in the field. CIPW normative calculations for these rocks suggest a primary mineral assemblage dominated by olivine (4 to 22%), hypersthene (32 to 62%), diopside (3 to 22%) and calcic plagioclase (13 to 21%) (Easton and Murphy 2002). The CIPW normative mineralogy suggests

that these rocks were originally olivine gabbronorites or olivine websterites, depending on whether they contained moderate or only minor amounts of plagioclase, respectively.

Orthopyroxene hornblendite bodies located near the Grenville Front contain euhedral bronzite grains up to 5 cm long. The bronzite grains become subrounded to rounded and overall grain size decreases with increasing distance from the Grenville Front. Similar observations can be observed from the margin to the core in some of the smaller hornblendite bodies. This change in bronzite form with increasing distance into the Grenville Province can be attributed to greater degrees of metamorphic recrystallization toward the interior of the Grenville Province.

Mineralogically, the orthopyroxene crystals in the bodies are complex and represent primary phenocrysts that recrystallized during regional metamorphism. Evidence that they were primary phenocrysts comes from the presence of zircon and chromite inclusions within the bronzite grains. Both types of inclusions contain well-developed cores and rims. In the case of the zircon grains, subrounded cores are surrounded by euhedral fractured rims. The cores yielded the aforementioned U/Pb age of 2468±5 Ma, whereas the rims yielded an age of 1471±10 Ma (Corfu and Easton 2000). Chromite cores are rimmed by iron chromite that typically forms only during regional metamorphism (Deer, Howie and Zussman 1966). Small euhedral zircons are also present in the fine-grained amphibole matrix and yielded an age of 1052±19Ma (Corfu and Easton 2000).

Mineral chemistry data on the matrix amphiboles indicates that they are magnesium hornblende, tremolite, cummingtonite and magnesium cummingtonite. The amphiboles occur both as individual grains and complexly exsolved and intergrown grains. Olivine grains from a body located near the Grenville Front have compositions of Fo_{73}. Orthopyroxene compositions lie in the bronzite field and are magnesium-rich (En_{75-80}) (Easton and Murphy 2002; Hubbard 1998).

Geochemistry

Analyses from 11 separate bodies show only a limited compositional range in major element chemistry (Easton 2003). The SiO_2 content of the unaltered orthopyroxene hornblendites ranges from 46.0 to 50.5 weight percent which is unusually high given the corresponding MgO content of 21.0 to 27.0 weight percent. On a Jensen diagram the data from the orthopyroxene hornblendites plot as a cluster in the peridotitic komatiite field although there is no evidence to suggest that these rocks were extrusive. Plots of Ti versus Cr and Cr-Ni are consistent with these rocks being crystallized from layered mafic sills.

Trace element data from orthopyroxene hornblendite samples plot in 2 distinct groups on chondrite-normalized rare earth element (REE) diagrams (Easton 2003). One group has a relatively flat, 10 times chondrite pattern with a negative Eu anomaly and total REE less than 35 ppm, whereas the second group has moderate light REE enrichment (to 60 times chondrite), no Eu anomaly, and total REE greater than 80 ppm. The REE content and high silica content of the orthopyroxene hornblendites suggests that they do not represent the most primitive rocks of the East Bull Lake intrusive suite.

The first group, characterized by low total REE contents and magnesium contents greater than 20 weight percent, occur as isolated bodies, near, but not intimately associated with other East Bull Lake intrusive suite rocks. In contrast, the second group with the higher REE contents and lower magnesium contents (<19.0 wt. %) occur at primary intrusive contacts, or as layers within East Bull Lake intrusive suite bodies. For example, hornblendite samples from the Street metagabbro plot in the LREE enriched group, as do olivine gabbronorites and pyroxenites from the River Valley intrusion. It can be argued that the two groups are related to one another, with the lower magnesium group being a more fractionated differentiate of the magma that produces these unusual rocks.

All unaltered orthopyroxene hornblendite samples contain from 2900 to 4700 ppm Cr and 750 to 1000 ppm Ni. Copper content is generally low (Easton 2003). Chromium is present as chromium-spinel, iron-chromite and chromite and is concentrated within olivine and orthopyroxene crystals. Platinum group element content in all of the analyzed orthopyroxene hornblendite samples is low (generally at or below detection limits), regardless of degree of alteration. The orthopyroxene hornblendites differ from other rocks of the East Bull Lake intrusive suite in their high chromium and nickel contents, as listed above. One explanation for this difference is that precipitation and removal of pyroxene from the primary magma (possibly by crystal settling) increases the silica content of the melt. The increase in silica would move the composition of the melt away from the olivine-chromite cotectic into the field of chromite and lead to the co-precipitation of bronzite and chromite. This process, in conjunction with olivine precipitation, would effectively strip the primary magma of much of its chromium and nickel, leaving rocks of the East Bull Lake intrusive suite with low chromium and nickel contents.

Chromium numbers of the orthopyroxene hornblendites are 20 to 38 and magnesium numbers are 78 to 82. The bodies have chemical affinities to high-aluminium chromitite from ophiolitic complexes, most notably, chromium number less than 50, TiO_2 greater than 0.2 weight percent, CaO greater than 1.5 weight percent, and Al_2O_3 greater than 1.2 weight percent. High aluminium chromitites are found in back-arc spreading and rifting tectonic environments that are consistent with previous suggestions of a rift-setting for the lower Huronian Supergroup (e.g., Bennett, Dressler and Robertson 1991).

Field Trip Guidebook

EAST BULL LAKE INTRUSION—OVERVIEW

Country Rocks, Structure and Geometry of the Intrusion

The East Bull Lake Intrusion, located roughly 80 km west of Sudbury (*see* Figure 1), is the type example of the East Bull Lake intrusive suite. The intrusion is hosted by a Neoarchean granite-greenstone belt to the southwest, but principally by tonalitic gneiss and syenite (James and Born 1985). The geometry of the intrusion (Figure 2) has been interpreted as primary (Peck, James and Chubb 1993; Born 1979) or as a result of polyphase open folding related to Penokean deformation (Vogel, James and Keays 1998). The East Bull Lake Intrusion consists of 2 interconnected magma chambers that locally exceed 1 km in thickness (*see* Figure 2). The eastern end of the East Bull Lake Intrusion is connected to the western end of the Agnew Lake Intrusion by the Streich dike (*see* Figure 2). The dike-like conduit that connects the eastern and western lobes of the East Bull Lake Intrusion (*see* Figure 2) consists of the lowermost stratigraphic units of the intrusion, and may represent part of the feeder dike to the magma chambers. These stratigraphically lowest parts of the intrusion are significant, as they are proximal to mineralized zones and feeder dikes that are largely obscured by the main mass of the lopolith. An unknown thickness of the upper part of the intrusion apparently has been eroded away. The East Bull Lake Intrusion was metamorphosed at the greenschist to lower amphibolite facies (Card 1978; Kamineni 1986; Chubb 1994). Igneous textures are typically well preserved throughout the intrusion, although primary pyroxene and olivine are commonly pseudomorphed by secondary amphiboles. Primary mineralogy has been deduced mainly from detailed textural and geochemical studies (e.g., James and Born 1985; Chubb 1994).

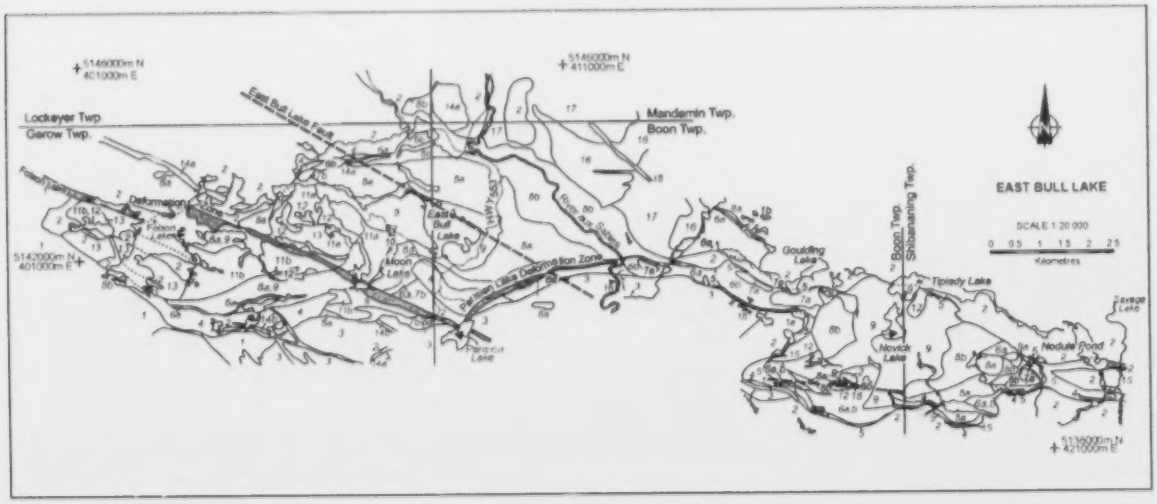

Figure 2. Geologic map of East Bull Lake Intrusion. Numbered units within the intrusion correspond to stratigraphic zones shown in Figure 3. Units 1 to 3 are Archean strata; units 14 to 17 are post-intrusion Paleoproterozoic units; for details see Peck et al. (1995).

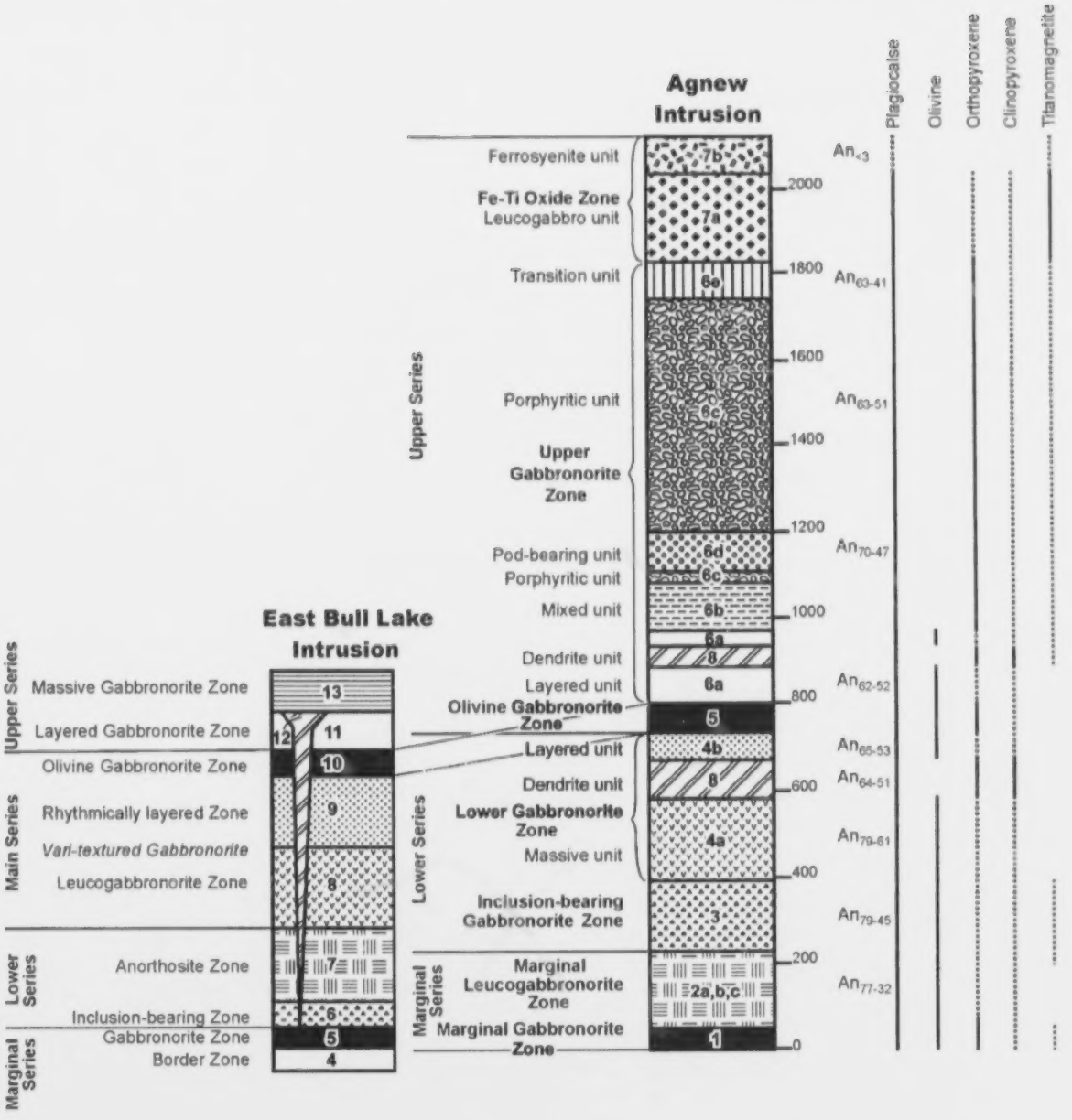

Figure 3. Stratigraphic sections for the East Bull Lake and Agnew Lake intrusions. Mineral distribution and plagioclase compositions are from Vogel et al. (1999). Unit numbers correlate with geologic maps shown in Figures 2 and 6a.

Stratigraphy and Petrography

The type stratigraphic section for the East Bull Lake Intrusion is shown in Figure 3. Three mappable subdivisions are recognized: the Lower, Main and Upper Series.

MARGINAL SERIES

The contact between the East Bull Lake Intrusion and Archean basement is represented by the Border and Gabbronorite zones of the Marginal Series. The Border Zone is commonly several tens of metres thick, and comprises varied proportions of gabbroic and anorthositic veins and locally derived basement xenoliths. The relative proportion of footwall xenoliths and gabbroic veins and the size of the basement xenoliths increase away from the intrusion and into the undisturbed basement. The basement xenoliths are commonly thermally recrystallized to hornfels and locally display evidence of *in situ* melting. Adjacent gabbroic veins commonly contain several percent quartz and/or patchy, granophyric-textured leucotonalite and leucogranite. The Border Zone is locally separated from the main mass of the intrusion by the Gabbronorite Zone, a 1 to 50 m thick texturally and modally banded gabbronorite. Chubb (1994) suggested that the Gabbronorite Zone, as exposed in the conduit linking the western and eastern lobes of the East Bull Lake Intrusion, probably developed from late injections of mafic magma that were unable to penetrate the overlying Lower Series rocks. Elsewhere in the East Bull Lake Intrusion, the Gabbronorite Zone is clearly gradational into the overlying Inclusion-Bearing Zone and underlying Border Zone, and likely represents an irregular chilled margin.

LOWER SERIES

The Lower Series hosts most of the known PGE mineralization in the East Bull Lake Intrusion, and comprises a lower inclusion-rich unit (Inclusion-Bearing Zone) and an upper anorthositic unit (Anorthosite Zone). The Inclusion-Bearing Zone consists of a matrix of medium- to coarse-grained gabbronorite and/or leucogabbronorite and a heterolithic inclusion suite. The inclusions typically represent only 1 to 10% of the unit and include basement xenoliths, anorthosite and leucogabbro autoliths and discontinuous, podiform pyroxenite and melagabbro bands and pods. The Anorthosite Zone consists of monotonous, coarse-grained anorthosite and leucogabbronorite. Locally, these anorthositic rocks are brecciated by crosscutting gabbroic vein networks. Spectacular "nodular" (glomerocrystic) textures occur in anorthositic rocks in the lower parts of the Anorthosite Zone. These occurrences are largely restricted to the conduit linking the west and east lobes and to the easternmost part of the east lobe. The nodular textures consist of tightly packed centimetre-size spheroidal aggregates of coarse-grained plagioclase in a matrix of coarse-grained pyroxenite and/or finer grained gabbronorite. The textures are believed to have formed due to enhanced cooling rates in the narrow parts of the intrusion (Chubb et al. 1995).

MAIN SERIES

The Main Series incorporates the Leucogabbronorite Zone, the Rhythmically Layered Zone and the Olivine Gabbronorite Zone (*see* Figure 3). Metre-scale, isomodal, phase layering becomes increasingly better developed upward through the Main Series (Photo 2). Igneous layering becomes better developed upward through the Main Series. In the Leucogabbronorite Zone, most of the layering reflects modal variations of plagioclase and pyroxene. Phase layering in the Rhythmically Layered Zone is typically caused by variations in olivine and plagioclase and like the underlying zone, overall, these rocks are leucocratic. The Olivine Gabbronorite Zone is distinct in having a high proportion of olivine-rich layers throughout its 50 to 70 m stratigraphy, relative to the underlying layered zones. Throughout the Main Series, modally graded layers typically become more plagioclase-rich upward. They are believed to have formed by separation of high-temperature, buoyant, cumulus plagioclase from dense, Fe- and Mg-rich residual magma ± olivine.

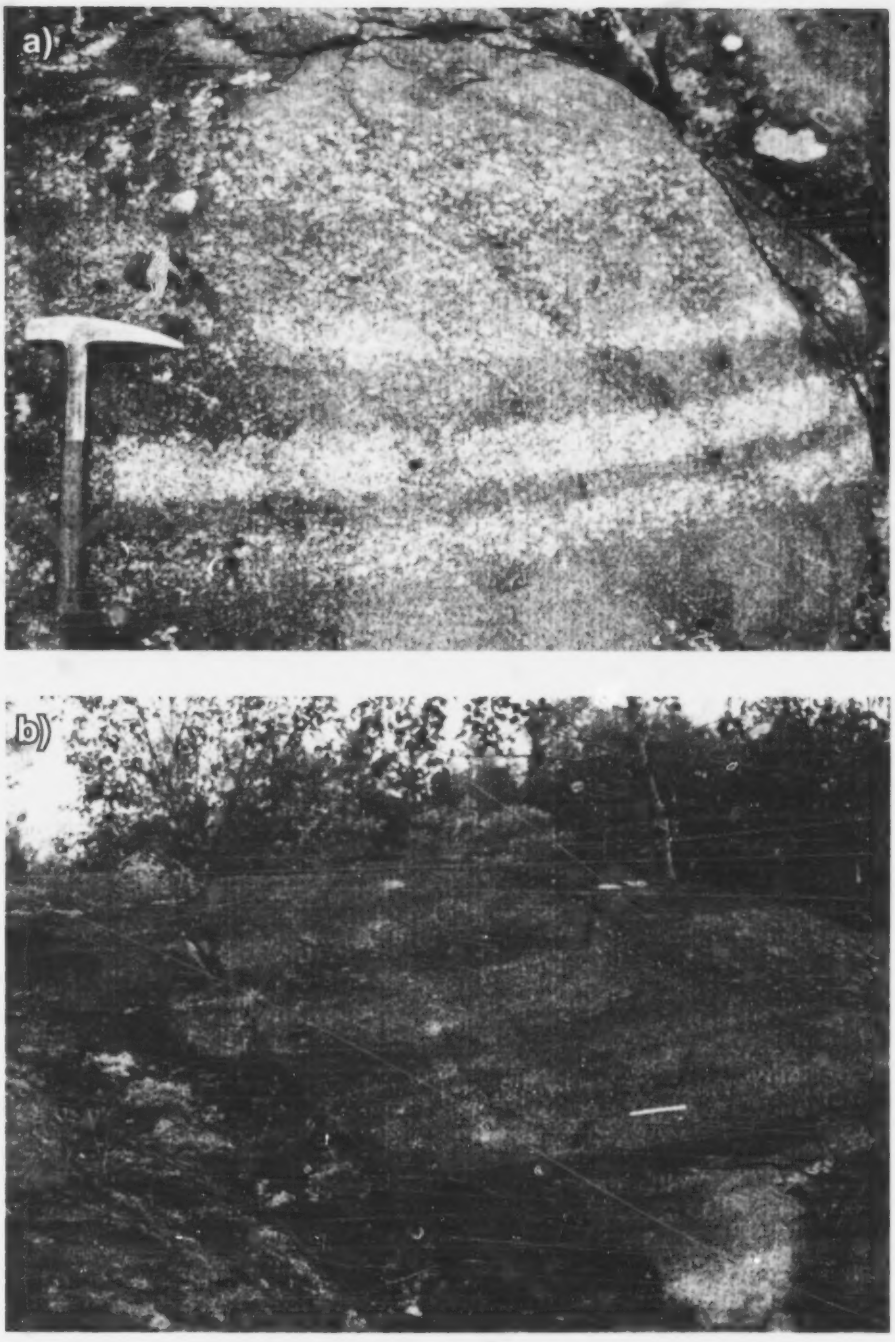

Photo 2. Igneous layering in the East Bull Lake Intrusion. **a)** Well-developed layering between plagioclase-rich and plagioclase-poor units. Hammer handle is approximately 30 cm long. **b)** More typical, subtle layering within gabbronoritic rocks of the Rhythmically Layered Zone, Main Series.

UPPER SERIES

The most chemically evolved rock types in the East Bull Lake Intrusion occur in the Upper Series, but they are less evolved than rocks present in the Upper Series of the Agnew Lake Intrusion (*see* Figure 3). Accordingly, it is believed that the uppermost parts of the East Bull Lake Intrusion have been eroded away. The Upper Series comprises the Layered Gabbronorite Zone and the Massive Gabbronorite Zone. The Layered Gabbronorite Zone consists of planar or disrupted, irregular, texturally and modally layered gabbronorite. The Massive Gabbronorite Zone comprises planar, fine- to medium-grained gabbronorite and ferrogabbronorite (Peck et al. 1995).

Varitextured gabbronorite occurs throughout the East Bull Lake Intrusion, forming irregular, metre-sized veins, pods and discontinuous layers that commonly display dendritic textures and have highly varied grain sizes (Photo 3). The thickest band occurs in the Layered Gabbronorite Zone to the west of Moon Lake (*see* Figure 2). Born (1979) mapped these rocks as a stratigraphic unit in the central plateau area of the East Bull Lake Intrusion. In the eastern part of the East Bull Lake Intrusion, these same rocks are not apparently stratigraphically controlled (Chubb 1994) leading to the schematic interpretation in Figure 3 of these rocks transecting stratigraphy. At the Agnew Lake Intrusion these same rocks form a distinctive stratigraphic unit as indicated in the stratigraphic section in Figure 3 (Vogel 1996).

The crystallization order throughout the East Bull Lake Intrusion is plagioclase ± olivine → orthopyroxene → clinopyroxene + magnetite → sodic myrmekite + apatite. Core plagioclase compositions vary from An_{70-80} in the Anorthosite Zone to near An_{60} at the top of the stratigraphy. Analyses of preserved igneous plagioclase, olivine and 2 pyroxenes in small areas of the Rhythmically Layered and the Olivine Gabbronorite zones (*see* Table 1) show Fo_{60-74} compositions for primocryst olivine. This suggests that the Olivine Gabbronorite Zone formed from a more primitive magma composition than the underlying Rhythmically Layered Zone. Where present, cumulus olivine appears to have co-precipitated with plagioclase and is commonly mantled and partly resorbed by orthopyroxene. Orthopyroxene includes hypersthene and iron-rich bronzite, whereas the dominant clinopyroxene is augite. Disseminated, chromium-rich spinel and clotty, coarse-grained magnetite locally occur within the Gabbronorite Zone (Marginal Series) in the southwestern part of the East Bull Lake Intrusion.

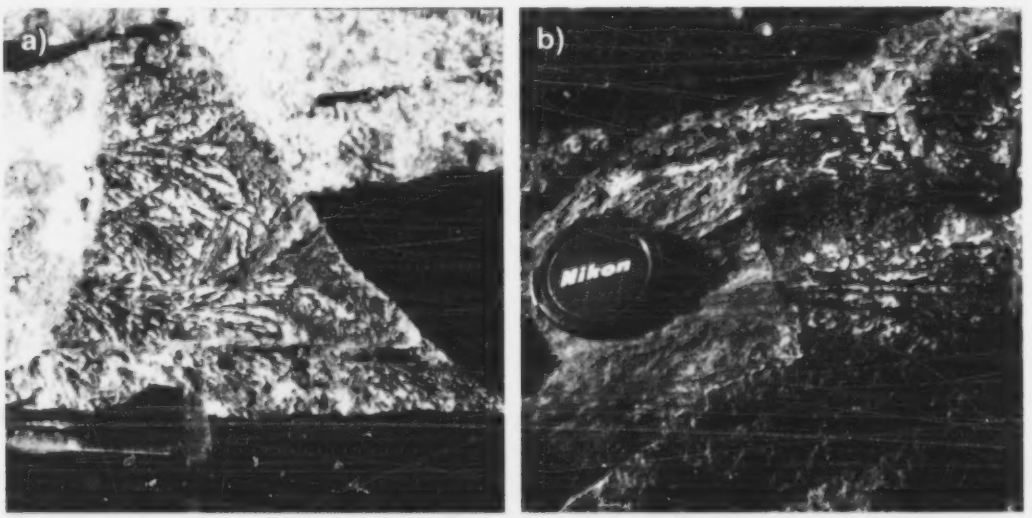

Photo 3. Dendritic texture within the Upper Series of the East Bull Lake Intrusion. **a)** Frond-like pyroxene dendrites. Hammer handle is approximately 30 cm long. **b)** Large, pyroxene-dendrites present just to the right of the 5.5 cm lens cap.

Geochemistry

A comprehensive geochemical database for the East Bull Lake Intrusion can be extracted from Peck et al. (1995) and Chubb (1994), which includes several hundred, whole-rock major and minor element analyses and selected trace and rare-earth element analyses. Additional, relevant geochemical data for the East Bull Lake Intrusion is contained in several Atomic Energy of Canada Ltd. publications (e.g., Ejeckam et al. 1990) and previous academic studies (Born 1979; James and Born 1985). Selected representative and average geochemical compositions for the major stratigraphic units in the East Bull Lake Intrusion are presented in Table 4 and illustrated in Figures 4 and 5. Included in Table 4 are 2 estimates of the parent liquid composition for the majority of the rocks in the East Bull Lake Intrusion. These are represented by a probable feeder dike (sample 91DCP291; Chubb 1994) from the eastern lobe of the East Bull Lake Intrusion, and a weighted bulk composition for the entire intrusion (Average WEBLI). The bulk composition was determined using the calculated volumes of all of the major stratigraphic units and their average chemical compositions. Both estimates give similar, Al-rich, low-Ti leucogabbroic magma compositions.

The East Bull Lake Intrusion is dominated by rocks having leucogabbronorite compositions that are olivine-normative in parts of the Lower Series and much of the Main Series. Detailed geochemical studies of surface and diamond-drill core samples from both the eastern and western lobes of the intrusion (e.g., James and Born 1985; Ejeckam et al. 1990; Chubb 1994; Peck et al. 1995) have shown that well-defined chemical fractionation trends are absent through the East Bull Lake Intrusion stratigraphy. This likely reflects the fact that

1. the early crystallization of the parent magmas was dominated by plagioclase with intermediate to calcic compositions that, as calculated by James et al. (2002a), were near neutrally buoyant in their Al-rich parent magmas.
2. the chamber was fed by multiple injections of chemically similar magma that became mixed with the resident magma, thereby precluding the development of chemical fractionation trends.

Nonetheless, some geochemical trends are present in the intrusion, a few of which are illustrated on Pearce-element ratio diagrams (*see* Figure 4) and chondrite-normalized rare-earth element plots (*see* Figure 5). In Figure 4a, Olivine Gabbronorite Zone rocks from the East Bull Lake and Agnew Lake intrusions (olivine-plagioclase cumulates) clearly form a more olivine-controlled group than do the rest of the samples from these intrusions. These data support the interpretation that intrusion of the Olivine Gabbronorite Zone magma represents a separate and more primitive magma pulse into the chamber. Figure 4b shows that plagioclase is the only significant calcium-bearing phase involved in the fractionation of the East Bull Lake Intrusion magma. This is consistent with petrography and rules out clinopyroxene as a mineral phase influencing fractional crystallization for this intrusion. In both Figures 4a and 4b, Upper Series rocks plot closer to the origin of the diagram reflecting their more fractionated compositions. Many of the mafic veins in the Border Zone are quartz normative and display field and geochemical evidence of significant assimilation of basement-derived, siliceous partial melts. Nevertheless, there is no evidence for significant contamination of the main body of magma in the East Bull Lake Intrusion through partial or total assimilation of country rock inclusions. The majority of the rocks in the lower parts of the East Bull Lake Intrusion are enriched in Al and depleted in incompatible trace elements in comparison to the proposed parent magma estimates (*see* Table 4, Figures 4a and 4b). The Main Series contains, on average, the most magnesian rocks in the East Bull Lake Intrusion, with olivine-plagioclase cumulates occurring throughout the Olivine Gabbronorite Zone and in parts of the underlying Rhythmically Layered Zone. The Upper Series contains the most evolved rocks in the East Bull Lake Intrusion, and on most chemical fractionation plots, fall at the evolved end of the fractionation trends (e.g., *see* Figure 4b).

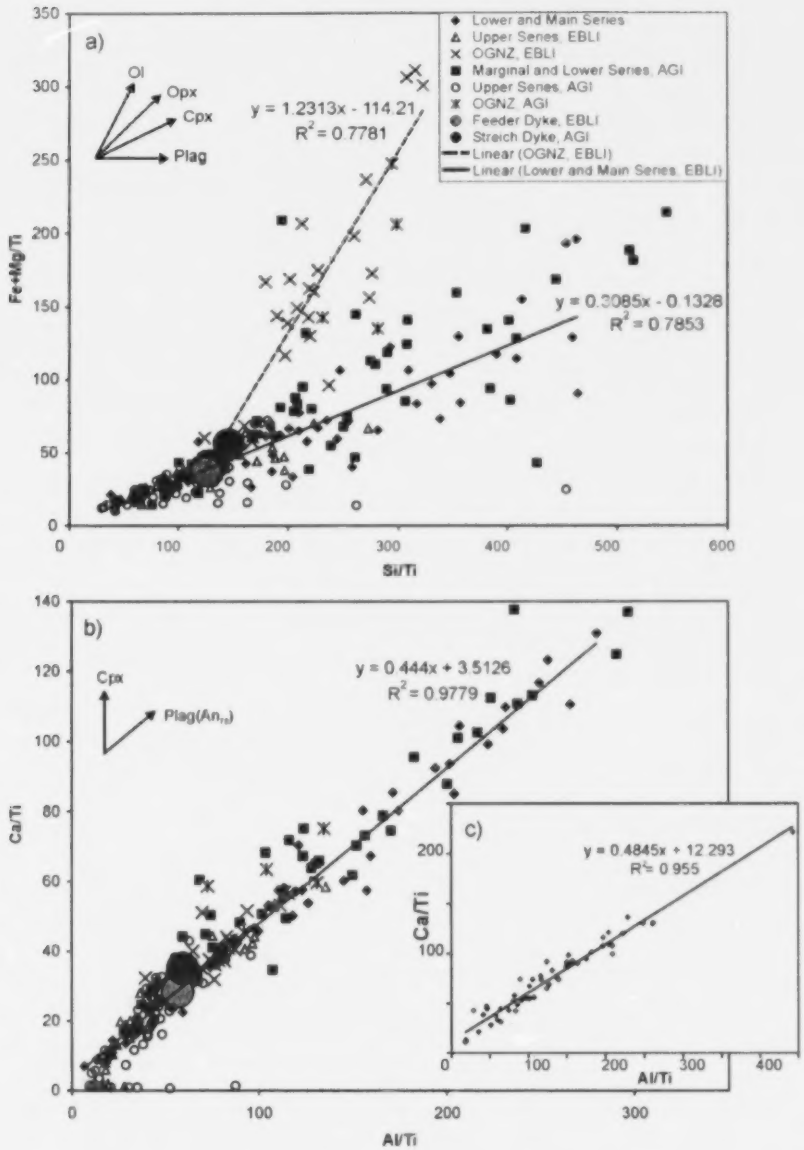

Figure 4. Pearce-element ratio diagrams for the East Bull Lake, Agnew Lake and River Valley intrusions. a) Fe+Mg/Ti versus Si/Ti plot for East Bull Lake and Agnew Lake intrusions. b) Ca/Ti versus Al/Ti plot for East Bull Lake and Agnew Lake intrusions. c) Ca/Ti versus Al/Ti plot for the River Valley intrusion. In figures 4a and 4b, solid symbols are for lower and middle portions of the stratigraphy, with open symbols for the upper part. The Olivine Gabbronorite Zone is shown separately as are the estimated parent magma compositions for the 2 intrusions. Solid lines are fitted curves for the East Bull Lake Intrusion, as examples. Mineral vectors indicate how the data should vary if trends are due to that phase only. The data in figures 4a and 4b show that the 2 intrusions exhibit identical chemical variations. In Figure 4a, Olivine Gabbronorite Zone rocks are clearly more mafic (primitive) in composition than the remainder of each intrusion which fall on a single trend with a much shallower (plagioclase-enriched) slope. The positions of the parent magma composition are consistent with the 2 groups being derived from cogenetic magmas. In Figure 4b, data for all samples fall on a linear trend with a slope in the range 0.40 to 0.45 indicating that calcic plagioclase feldspar mainly controls this trend, and that clinopyroxene is not a major modal phase in these rocks. In the lower left of 4a, samples of Upper Series rocks deviate from the trend near the origin of the diagram because they have primocryst ilmenomagnetite and thereby, Ti is no longer a conserved element. In figure 4c, rocks from the River Valley intrusion display a similar plagioclase-controlled trend, but with a greater proportion of samples lying closer to the origin, reflecting a slightly more mafic bulk composition of the samples.

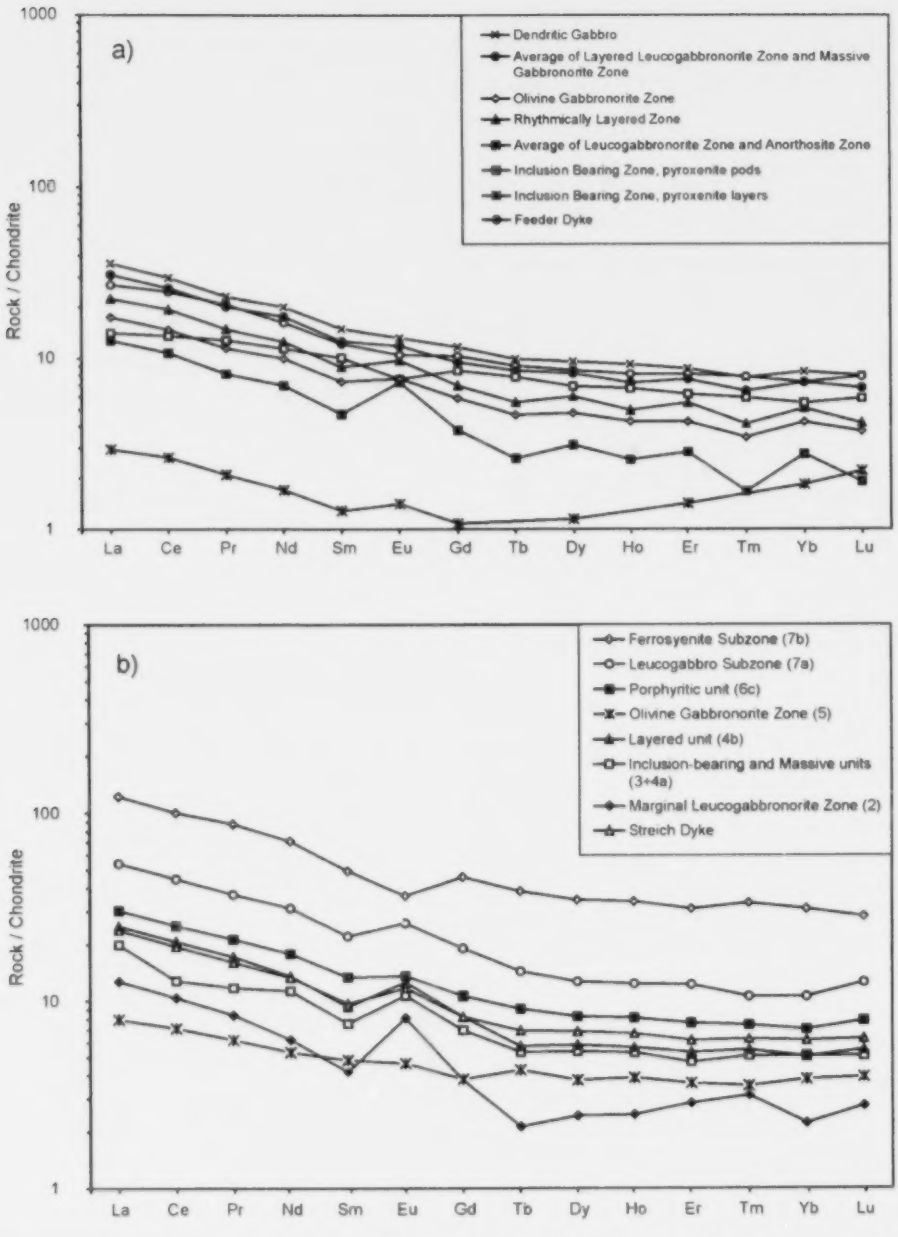

Figure 5. Chondrite-normalized rare earth element plots for the East Bull Lake and Agnew Lake intrusions. a) East Bull Lake Intrusion. b) Agnew Lake Intrusion. Data are from Peck et al. (1995) and Vogel (1996). Normalizing values are from Sun and McDonough (1989). In both diagrams, all data are the average for 2 or more samples. "Feeder dike" in Figure 5a and "Streich dike" in 5b are estimates of parent magma compositions to the East Bull Lake Intrusion and the Agnew Lake Intrusion, respectively. In 5a, note the U-shaped boninite-like pattern for pyroxenite layers from the Inclusion-Bearing Zone.

Figure 5a shows that all major rock types in the intrusion are enriched in light REE; this is typical for the East Bull Lake intrusive suite as a whole. The plagioclase-rich and cumulate character of rocks from the Lower and the Main Series in the East Bull Lake Intrusion is illustrated by their depleted total REE relative to the parent magma composition ("feeder dike"), and strong to moderate Eu anomaly.

Table 4. Representative and average anhydrous whole-rock geochemical analyses from the East Bull Lake and Agnew Lake intrusions (*from* James et al. 2002a).

Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Series	Basement	Basement	Marginal	Marginal	Marginal	Marginal	Marginal	Lower
Zone	Footwall	Footwall	Border	Border	Border	Border	GN	IBZ
Rock Type	Archean tonalite	Parisien Lake syenite	Anorthosite vein	Leucogabbro vein	Melagabbro norite vein	Quartz-rich gabbronorite vein	Gabbronorite EEBLI	Matrix, EEBLI
N	11	17	1	1	2	8	4	9
SiO_2	69.2	61.8	50.9	52.9	51.8	56.1	50.7	51.5
TiO_2	0.09	0.54	0.09	0.09	0.21	0.50	0.56	0.57
Al_2O_3	17.5	17.8	25.7	22.2	13.8	17.1	15.0	15.3
Fe_2O_3	1.70	4.19	2.74	4.34	9.72	8.17	13.6	12.2
MnO	0.02	0.09	0.04	0.08	0.20	0.13	0.19	0.19
MgO	0.44	1.16	2.24	4.88	11.9	5.33	7.55	7.67
CaO	2.89	2.48	13.3	11.1	10.4	9.13	9.63	9.79
Na_2O	6.94	5.36	4.28	3.80	1.71	2.72	2.21	2.24
K_2O	1.21	6.22	0.56	0.52	0.22	0.74	0.52	0.53
P_2O_5	0.04	0.27	0.08	0.08	0.08	0.09	0.06	0.06
Mg #	33.75	35.46	61.82	69.02	70.86	56.38	52.38	55.41
Cr	<10	<10	38	113	682	138	264	210
Ni	<5	8	51	107	392	192	201	244
Co	20	7	28	41	61	42	79	43
Sc	1.8	4.0	<1.0	<1.0	<1.0	15.2	39.1	19.4
V	16	53	32	39	131	153	340	127
Cu	12	17	377	88	922	214	188	209
Zn	31	77	31	50	112	70	99	67
Rb	23	201	27	24	20	27	19	16
Ba	784	1252	225	195	103	370	113	140
Sr	378	723	607	675	259	367	333	253
Nb	8.8	32.4	4.9	4.1	2.6	7.0	4.1	<1.0
Zr	74.6	550.6	37.8	37.5	24.4	73.7	62.7	34.9
Y	13.6	41.6	7.6	7.3	8.6	15.9	16.7	7.8

Analysis	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Series	Lower	Lower	Lower	Lower	Lower	Main	Main	Main
Zone	IBZ	IBZ	IBZ	Anorthosite	Anorthosite	LGN	RL	OGN
Rock Type	Pyroxenite pods, EEBLI	Pyroxenite layers, WEBLI	Chlorite schist, WEBLI	Anorthosite	Matrix to nodular anorthosite	Leucogabbro norite	Leucogabbro norite	Olivine gabbronorite
N	10	2	1	88	10	42	72	25
SiO_2	53.8	52.71	38.55	49.7	49.2	50.5	49.6	46.9
TiO_2	0.38	0.17	0.12	0.36	0.84	0.34	0.42	0.30
Al_2O_3	6.28	4.59	16.96	21.9	13.9	20.3	21.0	14.6
Fe_2O_3	13.5	14.15	20.74	7.67	13.1	8.09	8.28	13.4
MnO	0.23	0.21	0.26	0.12	0.19	0.13	0.12	0.18
MgO	17.0	23.76	17.99	5.50	10.0	6.46	6.16	14.5
CaO	8.12	4.29	4.77	11.6	10.8	11.1	11.1	8.19
Na_2O	0.52	0.05	0.56	2.52	1.49	2.44	2.58	1.56
K_2O	0.11	0.06	0.03	0.56	0.31	0.60	0.59	0.27
P_2O_5	0.05	0.01	0.02	0.05	0.12	0.05	0.06	0.04
Mg #	71.37	76.88	63.21	58.71	60.19	61.28	59.55	68.22
Cr	1360	87	998	116	289	155	81	230
Ni	383	403	2670	289	332	194	195	505
Co	87	59	152	40	96	41	40	90
Sc	<1.0	47	12	14.1	<1.0	17.2	17.2	13.1
V	196	152	100	120	296	100	127	104
Cu	80	1010	2000	338	72	95	80	91
Zn	116	95	365	69	97	71	72	91
Rb	15	<2	<2	21	19	26	24	15
Ba	51	<3	8	177	76	166	201	118
Sr	31	4	59	300	117	271	295	183
Nb	6.7	<1.0	<1.0	6.9	9.9	6.2	6.0	6.1
Zr	57.7	11	21	40.5	70.4	46.9	48.6	41.5
Y	17.3	2	3	11.2	24.3	11.1	12.1	14.4

Table 4. continued.

Analysis	17	18	191	20	21	22	23	24	25
Series	Main	Main	Upper	Upper	Dikes	Dikes	Dikes	Parent	Parent
Zone	LGN	LGN	GN	GN					
Rock Type	Gabbro-norite, Folson Lake	Gabbro-norite, Bull Lake	Vari-textured gabbro-norite	Massive gabbro-norite	Gabbro-norite dike, Folson Lake	Plagioclase-phyric dikes, WEBLI	Aphyric diabase dikes, WEBLI	Average WEBLI	Feeder 91DCP-291, Streich dike
N	24	30	29	32	6	8	11	342	1
SiO_2	51.2	52.2	51.7	52.9	51.0	51.3	41.0	50.2	50.8
TiO_2	0.52	0.69	0.65	0.90	0.80	0.80	1.22	0.45	0.54
Al_2O_3	18.1	18.1	15.6	15.3	15.8	15.0	14.1	19.5	19.6
Fe_2O_3	10.0	10.5	11.5	13.3	12.7	12.7	15.2	9.31	9.25
MnO	0.16	0.16	0.18	0.22	0.19	0.20	0.22	0.14	0.16
MgO	6.24	4.79	6.81	5.59	6.30	6.36	5.37	6.60	5.47
CaO	10.6	9.73	10.4	7.79	10.2	10.7	9.01	10.6	10.8
Na_2O	2.37	2.67	2.32	2.80	2.17	2.04	2.86	2.44	2.96
K_2O	0.76	1.07	0.71	1.13	0.74	0.73	0.89	0.65	0.30
P_2O_5	0.07	0.09	0.08	0.12	0.11	0.10	0.16	0.06	0.07
Mg #	55.25	47.48	53.90	45.46	49.60	49.74	41.13	58.41	53.94
Cr	138	72	184	63	136	89	69	125	153
Ni	121	92	113	67	116	85	65	224	140
Co	43	37	51	43	45	47	44	45	33
Sc	25.3	25.6	30.6	32.1	30.8	37.3	33.7	18.9	<1.0
V	167	200	220	264	235	250	310	142	171
Cu	90	182	121	138	138	119	153	179	66
Zn	85	85	90	125	97	97	120	80	70
Rb	27	42	27	46	34	35	44	26	8
Ba	258	328	245	392	260	224	312	211	93
Sr	261	255	223	193	210	230	239	267	261
Nb	6.3	<1.0	6.4	7.4	<1.0	<1.0	<1.0	6.5	2.5
Zr	60.2	66.8	68.3	100.8	80.5	67.9	116.6	52.5	65.0
Y	14.2	15.9	16.6	20.5	18.5	18.8	32.6	13.1	14.6

Notes: Major element oxides are in wt. %, trace element data are in ppm; Mg number = atomic Mg/Mg + Fe, where Fe = total Fe expressed as ferrous iron. All samples from Peck et al. (1995), except analyses 7, 8, and 13, which are from Chubb (1994).
Abbreviations: EEBLI = eastern East Bull Lake Intrusion; GN = Gabbronorite Zone; IBZ = Inclusion-Bearing Zone; LGN = Layered Gabbronorite Zone; OGN = Olivine Gabbronorite Zone; RL = Rhythmically Layered Zone; WEBLI = western East Bull Lake Intrusion.

Thermodynamic modelling of the crystallization of the East Bull Lake Intrusion based on the "feeder dike" parent magma (*see* Table 4), using the program COMAGMAT (Ariskan et al. 1993), suggests that plagioclase was the sole liquidus mineral over the temperature range 1300 to 1200°C, followed by olivine and then orthopyroxene (1176°C) (James et al. 2002a). The most robust model is in agreement with the predictions made by James and Born (1985), using Pearce-element ratio diagrams, who indicated that plagioclase accounts for nearly 85% of the phase volume of the fractionating assemblage in the Lower Series and 77% in the Upper Series. Orthopyroxene and clinopyroxene represent only about 20% of the phase volume throughout most of the East Bull Lake Intrusion, and olivine control is only evident in the middle to upper parts of the Main Series. The average Mg-number for the parent magmas is about 73, and the average, theoretical, plagioclase composition is about An_{73}. Our calculations also suggest that most of the pyroxenite pods in the Inclusion-Bearing Zone represent dense, fractionated, Mg- and Fe-enriched residual magma that originated in enclosing or overlying strata. Their REE-enriched character (*see* Figure 5a), relative to the main mass of Anorthosite Zone rocks, is consistent with this interpretation. There are, however, discontinuous, metre-scale, cumulate layers in the PGE-rich, basal part of the Inclusion-Bearing Zone along the southwest margin of East Bull Lake Intrusion (Bullfrog zone, Mustang Minerals Corporation) that have U-shaped REE profiles (*see* Figure 5a) indicating that they formed from boninitic magma. The origin and distribution of these atypical rocks requires further study, as they suggest that 2 magma types were present in the early (mineralized) stages of formation of this intrusion.

Mineralization

Mineral exploration in the East Bull Lake Intrusion began with prospectors who gained access along newly completed logging roads in the early 20th century. They focused their attention on gold and sulphide mineral prospects. Several companies, including Noranda Mines Ltd., El Pen-Rey Oil-Gas and Mines Ltd., Sylvanite Gold Mines Ltd. and the Mining Corporation of Canada Ltd., investigated the base metal potential of previously discovered sulphide mineral occurrences in the 1950s and 1960s. The PGE potential of the East Bull Lake Intrusion was first recognized by independent prospectors E. Gallo, M. Hauseux and S. Surmacz, as well as by BP Minerals. Their observations were corroborated by an extensive study of the mineral potential of the East Bull Lake Intrusion carried out by researchers from Laurentian University and the Ontario Geological Survey in the early 1990s (Chubb 1994; Peck, James and Chubb 1993; Peck et al. 1995). Both Inco and WMC International undertook small exploration programs on the East Bull Lake Intrusion, but sustained exploration did not take place due to low palladium prices and the unfamiliar mineralization style. Renewed exploration of the East Bull Lake Intrusion began in 1998, led by Mustang Minerals Corporation, whose property covers about 90% of the intrusion. The current exploration target is a bulk, near surface, low grade (e.g., 2.5 g/t Pd+Pt) PGE-copper-nickel resource suitable for open pit mining (Brisbin et al. 2001).

The geological environments for PGE-copper-nickel mineralization in the East Bull Lake Intrusion were first described in detail by Peck, James and Chubb (1993). They recommended the non-genetic term "contact sulphide mineralization" (now "contact-type") be used to describe all of the PGE-rich disseminated sulphide mineralization occurring in the Marginal and Lower Series of the intrusion. Sulphide mineralization is present throughout the Lower and underlying Marginal Series but is best developed within the Inclusion-Bearing Zone, within a few tens of metres of the footwall or sidewall contact. Recent diamond drilling by Mustang Minerals Corporation and Freewest Resources Canada Inc. has proven that this zone is typically 20 to 50 m thick and, despite the nugget-type distribution of the sulphide minerals, consistently displays an average sulphide mineral content of 1 to 2%. The sulphide minerals typically consist of approximately equal amounts of coarse chalcopyrite and pyrrhotite, and subordinate, finer-grained pentlandite. Where their original textures are preserved, the sulphide minerals in the Inclusion-Bearing Zone form coarse-grained blebs up to 3 cm in diameter. Sulphide minerals (<1 to 10%) also commonly occur in the Border Zone and the Gabbronorite Zone of the Marginal Series, but these occurrences are enriched in pyrrhotite and/or pyrite relative to the chalcopyrite-rich mineralization in the Inclusion-Bearing Zone. Sulphide minerals rarely occur in the Main and Upper Series and, where present, are principally composed of pyrrhotite and appear to have formed as late-crystallizing grains from trapped intercumulus liquids. In Olivine Gabbronorite Zone samples, however, disseminated fine-grained chalcopyrite and magnetite have been reported in the most altered rocks (James et al. 2002a) and may account for Pd+Pt+Au assays in the 0.5 to 1.0 g/t range from this unit (Peck et al. 1995, 2001).

Disseminated to massive sulphide minerals occur within the Parisien Lake deformation zone (PLDZ on Figure 2), a major east-trending structure. Most of the known mineralization is exposed in trenches located about 1 km east of East Bull Lake (*see* Figure 2). The sulphide minerals occur in metre-size, ovoid zones that are elongate parallel to the strike of the primary shear fabric in the Parisien Lake deformation zone. The sulphide minerals consist of pyrrhotite and lesser chalcopyrite, pyrite and pentlandite and are intergrown with quartz, amphibole, chlorite and magnetite. Field and geochemical data suggest that hydrous fluids permeating the Parisien Lake deformation zone leached chalcophile metals from pre-existing, magmatic sulphide mineralization in the deformed Lower Series rocks and redeposited them within dilatant zones.

The geochemistry and genesis of the contact-type PGE-copper-nickel mineralization in the East Bull Lake Intrusion is discussed in detail by Peck et al. (2001). Based on all available data, the mineralization

is characterized by highly varied whole-rock PGE grades that reflect the erratic distribution of the sulphide minerals on a hand sample scale. Diamond drilling confirms, however, that the average PGE grade of the Inclusion-Bearing Zone in the southwestern part of the East Bull Lake Intrusion is roughly 0.5 to 2.5 ppm combined Pd+Pt+Au. Analyses from grab samples range from typical values of 1 to 2 ppm to 43 ppm combined Pd+Pt+Au (sample collected by Freewest Resources Canada Inc. from a trench on their Folson Lake property). Data presented by Peck et al. (1995) show that 20% of all of the reconnaissance samples collected from the Lower Series in the western lobe of the intrusion contain greater than 1 ppm combined Pd+Pt+Au, with an average Pd content of approximately 200 ppb. These values represent highly anomalous background PGE contents in comparison to most other mafic or ultramafic intrusions. For comparison, barren norites, pyroxenites and harzburgites from the Lower, Critical and Main Zones of the Bushveld Complex have values ranging from 13 to 478 ppb Pt+Pd (Barnes and Maier 1999). Average Pd/Pt ratios are highest in the Anorthosite Zone (3.2 to 4.3) and lowest in the pyroxenitic pods of the Inclusion-Bearing Zone (1.56) and the Border Zone (2.0). Average Cu:Ni ratios range from 0.6 in samples from the matrix in Inclusion-Bearing Zone to 4.8 in the pyroxenitic pods; however, most samples have values between 2 and 3. Border Zone sulphide occurrences have the lowest average PGE grades (at similar total sulphide mineral abundance), but show a considerable range in abundance. Average S/Se ratios for the PGE-rich sulphide mineralization range from 1240 to 2840, which are within the empirically-determined range for mantle-derived sulphide mineralization (Eckstrand et al. 1989), and are indicative of a magmatic origin for the contact-type PGE mineralization. Copper displays a strong positive correlation with both S and Se. Pd and Pt display significant, positive, correlation with each other, with Cu and, to a lesser degree, with S.

As is typical of most mafic-hosted magmatic sulphide mineralization, the contact-type sulphide mineralization in the East Bull Lake Intrusion shows strong enrichment of the low-melting point PGE (e.g., Pd, Pt) relative to the refractory PGE (Ir, Rh, Ru) on a chondrite-normalized chalcophile metal plot (James et al. 2002a). The structurally-controlled sulphide mineralization from the Parisien Lake deformation zone show lower PGE contents per unit sulphide in comparison to the contact-type mineralization. The former sulphide mineralization type also have much higher Pd:Ir ratios, a feature consistent with the known differences in degree of mobility of Pd versus Ir during hydrothermal alteration of mafic and ultramafic rocks (Keays et al. 1982).

ROAD LOG, DAY 1, EAST BULL LAKE INTRUSION

Note: Highway 533 is used regularly by logging trucks. Consequently, extreme caution should be taken when parking vehicles on the shoulder and when examining outcrops along Highway 533.

Geological map reference: Chubb, Hannila and Peck (1994).

0.0 km	Start at the junction of Highway 69S and the Highway 17W bypass in Sudbury. Set odometer to zero. Drive west on Highway 17 to Massey.
0.4 km	Junction of Highway 17W bypass and Regional Road 80 (Long Lake Road), continue west on Highway 17 bypass.
70.9 km	Junction of Highway 17 and 6, just north of Espanola. Continue west on Highway 17.
97.0 km	Junction of Highway 17 and 553 in Massey. Turn right (north) onto Highway 553 toward East Bull Lake.
119.9 km	Pull over on shoulder of Highway 533 at the top of a high ridge. Examine cleaned outcrops on both sides of the highway.

Stop 1. Paleoproterozoic Metagabbro

The high ridge consists of a linear(?) body of massive, medium-grained, metagabbro which may represent part of a feeder system to other East Bull Lake intrusive suite sills that have been eroded from the surrounding terrain. Prevec (1993) suggested that the rocks from this stop have a suitable parent composition for the East Bull Lake Intrusion. Alternatively, these rocks could be part of a large Matachewan diabase dike, but unlike most of the Matachewan dikes, it is not plagioclase-phyric. Return to vehicles and continue north on Highway 533. UTM 408177E, 5133860N.

122.4 km Power line crosses the Highway, continue north.

124.8 km Approximate southern margin of the Neoarchean Parisien Lake syenite (2665±2; Krogh, Davis and Corfu 1984).

125.3 km Junction of Highway 533 and logging road to the east. Park vehicles and walk a short distance east along the logging road to examine outcrops on the south and north sides of the logging road.

Stop 2. Neoarchean Parisien Lake Syenite

At this locality we see small amounts of coarse-grained syenite showing a well-developed igneous flow fabric on a local scale, as well as more abundant exposures of massive, medium-grained syenite. Regional mapping indicates that several types of medium-grained syenite intrude the coarser-grained variety; the latter is the more abundant rock type in the body. The Neoarchean age of the syenite is distinct from the 2470 to 2490 Ma age range of the East Bull Lake intrusive suite (*see* Table 2). These rocks form the footwall to the East Bull Lake Intrusion at Stop 12b. Return to vehicles and continue north on Highway 533.

126.0 km Low outcrops on the east side of Highway 533 consist of a plagioclase-phyric diabase dike typical of the Matachewan dike swarm. The dike contains greenish altered plagioclase phenocrysts in a fine-grained metadiabase matrix. Mafic diabase dikes, some plagioclase-phyric, but many not, intrude both the Archean basement and the Parisien Lake syenite. Many of the same dikes also intrude the East Bull Lake Intrusion. A few very large dikes do not cut the intrusion, and are interpreted to be potential feeders to the sills to the East Bull Lake intrusive suite bodies in this area and elsewhere in the Southern Province. Typically, the dikes strike to the northwest, but they also strike west to west-northwest when they are proximal to the Southern–Superior province boundary.

126.5 km Outcrop of coarse-grained syenite, in the central part of the Parsien Lake syenite. The outcrop is intruded on its south side by a 10 to 20 m wide, northwest-trending, Matachewan diabase dike.

127.6 km Pull off to shoulder just past the curve in road where the highway passes between 2 large outcrop ridges. Leave vehicles and work your way up to the top of the large ridge on the west side of the road.

Stop 3. Southern Margin of the East Bull Lake Intrusion

This area of the East Bull Lake Intrusion forms a high ridge of very coarse-grained, massive varitextured leucogabbronorite. At its southern extremity, it is inclusion-bearing and sparsely mineralized. The outcrop area represents both the Inclusion-Bearing and Anorthosite zones, of the Lower Series, inward of

the intrusion contact. At this locality, the contact with the Parisien Lake syenite is sharp and most likely is a fault. Return to vehicles and continue north on Highway 533.

128.0 km Folson Lake deformation zone. At this location Highway 553 is "offset" to the east due to this major shear zone that strikes northwest across the entire intrusion (*see* Figure 2).

128.7 km Pull off to the shoulder and examine low outcrops on both sides of the road exposed on a curve as it passes over a small rise.

Stop 4. Country Rocks

These outcrops consist of country rocks of the Neoarchean Ramsay–Algoma gneiss complex. The Ramsay–Algoma gneiss complex (Jackson and Fyon 1991) is intruded by both the Parisien Lake syenite and the East Bull Lake Intrusion. Typically these gneisses are mixtures of strongly foliated granitic gneiss and metatextite to diatextite that enclose strongly deformed enclaves of mafic gneiss that likely represent remnants of greenstone belt metavolcanic rocks and/or diabase dikes. UTM 408300E, 5141425N.

128.8 km Parisien Lake road leads to mineralized zones along southern contact of the East Bull Lake Intrusion.

129.3 km Junction to the west between Highway 533 and the AECL (Atomic Energy of Canada Limited) road. The AECL road leads to Moon Lake, Central Plateau and the Folson Lake deformation zone.

129.8 km Outcrops present in this sandpit, 30 m east of Highway 533, expose metre-scale isomodal phase layering in the Rhythmically Layered Zone, Main Series, East Bull Lake Intrusion. The layering consists of thin leucogabbronorite layers (with scarce olivine primocrysts) that pinch and swell in thickness and continuity, and metre-thick isomodal layeres of olivine melagabbronorite. Boundaries between the layers are sharp (similar to Photo 2a). Outcrops at the road at this locality show graded layers, as well as layers with more gradational boundaries (similar to Photo 2b). UTM 409022E, 5142098N.

130.5 km East Bull Lake Lodge just to the west of Highway 533. Lodge is owned by Gerry Vauteur.

130.7 km Pull over and park where space is available. Examine vertical faces in outcrop on the west side of the road.

Stop 5. Rhythmically Layered Zone

This stop is located within the Rhythmically Layered Zone of the Main Series of the East Bull Lake Intrusion. On the west side of the road, vertical faces in outcrop exhibit several 0.3 to 1 m thick layers that dip west into the outcrop at 20 to 30°. The layers contain primocrysts of olivine and plagioclase enclosed in a matrix of orthopyroxene and clinopyroxene. Typically within the East Bull Lake Intrusion, all of the mafic minerals are replaced by secondary amphiboles, but plagioclase is commonly preserved. In this outcrop, however, well-formed outlines of olivine are easily observed; their proportion changes abruptly across layer boundaries. Layer compositions vary from olivine leucogabbronorite to olivine melagabbonorite; in all cases the layer boundaries are typically sharp and evidence of grading is very sparse. In this outcrop, evidence of a gravity-driven convection system is negligible.

Return to vehicles, turn around and retrace route south to the junction of Highway 533 and the AECL road. Turn on to the AECL route and follow it to the end. Park vehicles in the pullout area (UTM 409405E, 5142725N), and walk south along the trail to a series of stripped outcrops.

Stop 6. Folson Lake Deformation Zone

Be careful of your footing on these smooth outcrops if the surfaces are wet. At this locality the Folson Lake deformation zone intersects the Layered Gabbronorite Zone of the Upper Series of the East Bull Lake Intrusion (*see* Figure 2). Kamineni et al. (1984) refer to this altered gabbronorite that extends as a narrow zone along the northwest-trending Folson Lake fault as the "Stockwork Gabbro". It contains a complex network of at least 2 generations of quartz veins as well as feldspar veins (both plagioclase and adularia); that together comprise up to 30 volume per cent of the rock. Diabase dikes transect the altered gabbro stockwork both parallel and perpendicular to the northwest-striking zone of deformation and faulting. Petrological studies of the gabbros in this and related areas by Kamineni et al. (1985) indicate that the regional greenschist facies to epidote-amphibolite facies mineralogy is altered on a local scale to minerals characteristic of prehnite-pumpellyite facies and zeolite facies (e.g., laumontite, analcite, calcite). UTM location at parking area is 406330E, 5142108N. Return to vehicles.

0.0 km Reset odometer to zero and head east toward Highway 533.

0.8 km Park at edge of road by large outcrop.

Stop 7. Dendritic Texture in the Varitextured Gabbronorite Zone

This outcrop is located in the Varitextured Gabbronorite Zone, Upper Series, East Bull Lake Intrusion. Pods and lenses, 0.5 to 1.0 m in maximum dimension, of coarse-grained, pegmatitic and dendritic gabbronorite occur sporadically in the massive, medium-grained gabbronorite host rock. The rapid textural variation is diagnostic of this zone, as is the appearance of pyroxene dendrites forming frond-like feather patterns in a plagioclase matrix (*see* Photos 3a, 3b). Rarely, the feldspar also exhibits this growth pattern. At this locality the dendritic pegmatites occur as pods; elsewhere (e.g., Agnew Lake Intrusion) they have been observed in layer-like zones, dendrites pointing upward, reminiscent of crescumulate textures. In the East Bull Lake Intrusion, rocks hosting these textural varieties of gabbronorite have been mapped by Born (1979) as a conformable stratigraphic zone of the Upper Series of the intrusion. More recently, D Peck and P. Chubb have interpreted these rocks as late diapiric melts that were intrusive into the pre-existing stratigraphy. UTM 406755E, 5142610N. Return to vehicles, continue east.

1.1 km Park at edge of road by large outcrop.

Stop 8. Layered Gabbronorite Zone

This outcrop exposes delicate small-scale, centimetre- to decimetre-scale layering in the Layered Gabbronorite Zone, Upper Series. Unlike the layering observed so far today, there is the suggestion here of current action and erosion of earlier formed cumulates suggestive of either active convection or slumping and/or soft sediment deformation of units. Rock compositions in the lower part of the outcrop are medium-grained gabbronorite, whereas at the top of the outcrop it is a coarse-grained leucogabbronorite. UTM 406900E, 5142790N. Return to vehicles, continue east.

2.2 km Park at edge of road in pullout area. To reach this stop, head downhill toward the north end of Moon Lake. Cross the beaver dam at the end of the lake and follow the slope roughly ~200 m to the south to an area where scattered low-lying outcrops occur on the west side of Moon Lake at the base of the central plateau. **This traverse should not be made alone and should be only conducted using appropriate footwear and field equipment.**

Stop 9. Olivine Gabbronorite Zone

This stop is located in the Olivine Gabbronorite Zone, within the uppermost part of the Main Series of the East Bull Lake Intrusion. Rocks of this zone occur as metre-scale layered sequences with the more mafic olivine-rich cumulates forming the dominant rock types interspersed with thin, leucocratic plagioclase-dominant layers. In these rocks olivine, plagioclase and occasionally orthopyroxene are primocryst phases. Olivine and plagioclase compositions are more primitive than in zones above and below this sequence. The Olivine Gabbronorite Zone is interpreted to represent an influx of more primitive magma into the magma chamber which interrupted the fractional crystallization process that links the Rhythmically Layered Zone of the Main Series with the Layered Gabbronorite Zone of the Upper Series. UTM 407370E, 5142942N. Return to vehicles, continue east.

2.6 km Park alongside the road where possible. Stop 10 is located on an outcrop about 20 m west of the AECL road.

Stop 10. Rhythmically Layered Zone, East Bull Lake Intrusion

This outcrop shows metre-scale layering in rocks of the Rhythmically Layered Zone, Main Series, that have a typical shallow dip to the west. At the road, these rocks are cut by a 5 to 10 m wide, northwest-trending diabase dike. As previously noted, such dikes are abundant throughout the intrusion. UTM 407585E, 5142708N. Return to vehicles, continue east.

3.3 km Park on the west side of the road in small pullout area. This stop is a kilometre-long walk through the units that form the margin (bottom or sidewall) of the East Bull Lake Intrusion in the Moon Lake area. The trace of the traverse is shown in the accompanying map of this area (Figure 6) that was prepared by D. Peck and P. Chubb. **This traverse should not be made alone and should be only conducted using appropriate footwear and field equipment.**

Stop 11. Moon Lake Traverse

Stop 11 is a traverse through the Lower Series and the Border Zone of the intrusion, which are both areas where disseminated copper-PGE mineralization is common. The Border Zone (*see* Figure 6, units 4a to 4e) represents footwall and/or sidewall lithologies to the main intrusion. It consists of Archean gneissic and metaplutonic rocks that are intruded by, or which contain, irregular to linear zones of anorthosite, leucogabbnorite and gabbronorite that appear to be related to the East Bull Lake Intrusion. The Border Zone is in abrupt contact with the Lower Series, which at this locality consists of the Inclusion-Bearing Zone (*see* Figure 6, units 6c and 6d) and the Anorthosite Zone (*see* Figure 6, unit 7a and 7b). Sulphide mineralization occurs in units 6c and 6d (Inclusion-Bearing Zone) proximal to the margin of the intrusion; leucogabbronorites in these units are typically very coarse grained, commonly varitextured, variably inclusion bearing, and show no evidence of layering. Xenoliths and autoliths vary from abundant to scarce to absent; they are typically 1 to 10 cm in maximum dimension. Autoliths vary in composition from pyroxenite to anorthosite.

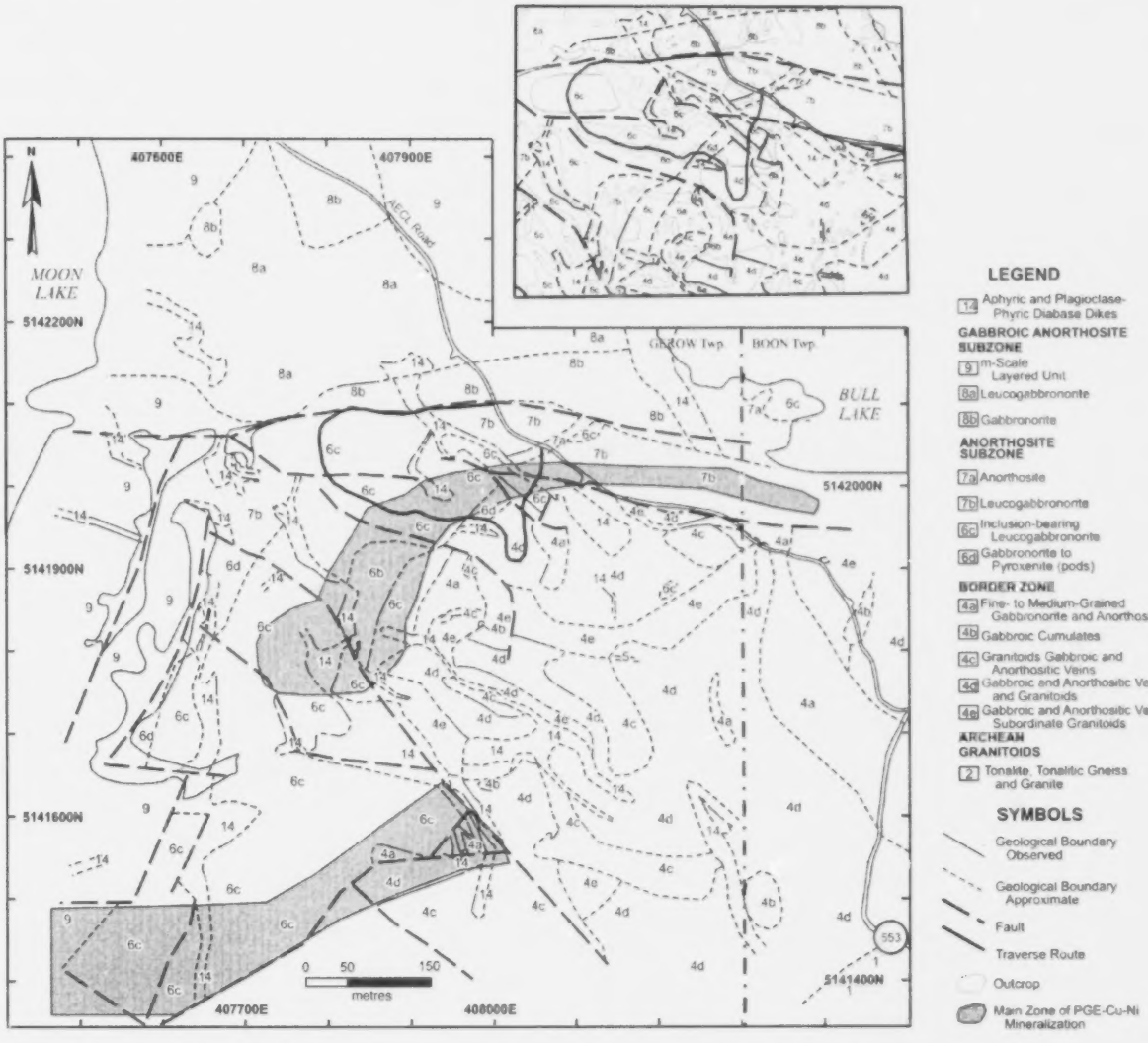

Figure 6. Geological map of the Moon Lake area, East Bull Lake Intrusion, showing the route of the traverse (heavy line) undertaken during Stop 11. Shaded areas indicate areas of disseminated sulphide mineralization. D.C. Peck and P.C. Chubb originally prepared the map in 1991 for the Department of Earth Sciences, Laurentian University. Inset map in the upper right indicates in detail the route of the traverse, as well as outcrop areas crossed during the traverse. Numerical rock codes in the legend correspond to those used in Figures 2 and 3, and on the map of Chubb, Hannila and Peck (1994). Note that UTM co-ordinates in this figure are in Zone 17, datum NAD 27.

Trace to 3% disseminated chalcopyrite, pyrrhotite ± pentlandite and pyrite ocurs in these units. Typically the sulphide minerals are medium- to coarse-grained aggregates in an epidote (saussurite)-rich zone of alteration in plagioclase, and also as much finer grained xenoblasts in the same silicate minerals. The sulphide mineral assemblage appears to have both a magmatic and metamorphic and/or hydrothermal paragenesis. In these rocks Cu+Ni = 0.1 to 0.5 wt %, with Cu>Ni, and Pd+Pt = 0.5 to 10g/t and Pd/Pt = 1 to 5. The Anorthosite Zone (*see* Figure 6, units 7a and 7b) consists of coarse- to very coarse-grained massive anorthosite and leucogabbronorite. Altered pyroxenes locally occur as coarse-grained interstitial anhedral to subhedral crystals and also as 1 to 10 cm zones (aggregates of crystals) that are interpreted to have formed from fractionated interstitial liquids due to prolonged early crystallization of plagioclase feldspar. As illustrated in the inset map in Figure 6, the traverse route encounters the following sequence

of rock types: units 7a and 7b (Anorthosite Zone); unit 6c (Inclusion-Bearing Zone), unit 4a (Border Zone), units 6d and 6c (Inclusion-Bearing Zone).

The shaded area in Figure 6 shows the general distribution of the PGE mineralization, which may be associated with disseminated sulphide minerals. Some more specific data on the mineralization in the Moon Lake area is given below, summarized from detailed information presented in Peck et al. (1995, Appendix 5, Part A). Border Zone (unit 4) rocks related to the East Bull Lake Intrusion include gabbro, quartz gabbro and leucogabbro. Unlike the sulphide mineral assemblage in the Lower Series of the intrusion, pyrite is particularly abundant. In this zone Pd+Pt normally does not exceed 700 ppb with Pd/Pt ≈ 2. Cu+Ni is in the range 80 to 1300 ppm and typically Cu ≈ Ni.

Mineralization in the Inclusion-Bearing Zone shows a range in Pd+Pt = 150 to 3000 ppb and Pd/Pt = 2 to 6; with Cu+Ni = 700 to 7000 ppm and Cu/Ni = 2 to 4. The data that is reported by Peck et al. (1995) indicates that the range and ratios for the PGE, Cu and Ni for the Anorthosite Zone are very similar to those for the Inclusion-Bearing Zone. Unpublished semiquantitative data collected by D. Peck and B. Jago on the platinum group minerals in 2 samples from the Inclusion-Bearing Zone in the Moon Lake area indicate that the PGE in the samples comes from 1 to 10 micron-size grains of sperrylite, moncheite, Bi-kotulskite and platarsite/hollingsworthite. These phases are normally found at grain boundaries of one or more of chalcopyrite, actinolite, epidote, albite or quartz, or within the silicate minerals in fractures or cleavage planes and much less commonly in chalcopyrite.

Return to vehicles, continue east on AECL road to Highway 533.

4.0 km Junction of the AECL road and Highway 533. Turn south (right) onto Highway 553.

4.5 km Junction, Highway 533 and Parisien Lake trail on the east side of the highway. The trail is poorly marked and partly overgrown by saplings. To reach the key outcrop areas of Stops 12A and 12B, walk east on the trail for 20 to 30 minutes to a stripped north-trending ouctrop area (Stop 12A). Following examination of these stripped outcrops, continue east to a large east-trending stripped area (Stop 12B). The 2 stripped areas expose rocks of the Marginal and Lower Series, and associated mineralization along the south side of the East Bull Lake Intrusion, respectively. **This traverse should not be made alone, and should be only conducted using appropriate footwear and field equipment.**

Stop 12A. Parisien Lake Traverse

This series of north-trending, stripped outcrops lies perpendicular to the contact of the East Bull Lake Intrusion, and consists of rocks of the Border Zone (footwall lithologies) and mineralized leucocratic rocks of the Lower Series. Walking north from the southernmost outcrops in the Border Zone, one observes layered Archean metasedimentary gneisses intruded by Parisien Lake syenite. Both rock types are in sharp contact on the north side of the outcrop with a Matachewan plagioclase-phyric diabase dike; an alternative interpretation is that the diabase represents a unit of the Gabbronorite Zone in the Marginal Series. The north side of the diabase is in sharp fault (?) contact with a 3 to 5 m thick, lens-shaped zone of sulphide-rich metapyroxenite to peridotite. The silicate minerals in this zone consist of pyroxene and/or olivine replaced by medium-grained calcic amphibole (tremolite?) enclosed and intergrown with fine- to medium-grained magnetite-chalcopyrite-pentlandite. The opaque-rich material in the zone is typically a foliated, medium- to coarse-grained, calcic amphibole-magnetite-pyrite-pyrrhotite assemblage. To the north of this mafic autolithic zone is a 20 m thick unit of varitextured leucogabbronorite which has abundant disseminated interstitial magmatic pyrrhotite-chalcopyrite-pentlandite and minor pyrite mineralization. Locally the silicate mineral assemblage has been altered to rusty zones of fine- to medium-grained biotite-actinolite-chlorite-feldspar and up to 5% idioblastic tourmaline (no sulphide

minerals). Platinum group element content in grab samples range from 1.4 to 2.4 g/t; channel samples have analysed 0.84 g/t over 21 m, including 1.36g/t over 6 m. This rock becomes "flinty" in the northernmost part of the stripped outcrop, probably reflecting mylonite development proximal to the Parisien Lake deformation zone.

Continue to walk east along trail. Roughly 3 minutes to the east, you will encounter a long series of stripped outcrop that are oriented subparallel to the trail.

Stop 12B. Parisien Lake Traverse

The dominant rock type is coarse-grained leucogabbronorite, with lesser amounts of melagabbronorite, at the west and north ends of this large stripped outcrop. Some of the melagabbronorite could be interpreted as disrupted dikes. In a few places discontinuous, sinuous, steeply dipping, centimetre- to metre-scale layering is observed in the leucogabbronorites. The orientation of the layering is subparallel to the margin of the intrusion. Both rock types host disseminated sulphide minerals. Convoluted boundaries with reaction zones indicate interaction between the leucogabbronorite and the melagabbronorite, suggesting that magma mixing occurred between these phases. At the east end of the stripped outcrop area, leucogabbronorite is in sharp contact with Parisien Lake syenite. This contact represents the boundary between the Lower and Marginal Series of the intrusion. UTM co-ordinates at the east end of the stripped area are 409788E, 5141490N.

This concludes Day 1. Retrace route back to Highway 533.

AGNEW LAKE INTRUSION—OVERVIEW

Country Rocks, Structure, and Geometry of the Intrusion

This section is largely based on data reported in Vogel (1996), Vogel, James and Keays (1998) and Vogel et al. (1999). The main mass of the Agnew Lake Intrusion is located on the west side of Agnew Lake, roughly 65 km southwest of Sudbury (*see* Figure 1). It is similar in age and size to the East Bull Lake Intrusion (2491 versus 2480 Ma and 50 km^2 *versus* 43 km^2, respectively, *see* Table 2). It is linked to the East Bull Lake Intrusion, on its northwest side, by the Streich dike, a 200 to 300 m wide composite body with a strike length of approximately 10 km. Pink to white, coarse-grained granites and orthogneisses of the Neoarchean Ramsay–Algoma gneiss complex (Jackson and Fyon 1991) form the footwall rocks to the intrusion around its north, west, and south sides (Figure 7a). There are only rare occurrences of footwall breccia zones at the intrusion's contact with the granitic rocks equivalent to the Border Zone of the East Bull Lake Intrusion. More commonly there is an abundance of felsic dikes (thermal aureole partial melts) intruding older granitic basement rock, particularly where mafic (feeder) dikes are abundant near the intrusion contact. The east margin of the intrusion is in fault contact with, or is apparently unconformably overlain by, McKim Formation metasedimentary rocks of the Huronian Supergroup (*see* Figure 7a).

The longitudinal axis of the Agnew Lake Intrusion is 110 to 120° (*see* Figures 7a and 7b), which is parallel to the axis of the East Bull Lake Intrusion, the Streich dike and Matachewan diabase dikes in the southernmost Superior Province (Halls and Bates 1990). This trend is thought to reflect the orientation of the rift structure that permitted magma intrusion. The attitude of igneous layering in the intrusion is illustrated in Figure 7b. It shows that the body has an asymmetric (synclinal) shape with the axis of the structure plunging gently northeast. Its axial plane is parallel to that of Penokean folds in younger Huronian Supergroup strata. This fact and its high angle of intersection with the longitudinal axis of the intrusion and Streich dike, suggests that the present geometry of the Agnew Lake Intrusion is due to Penokean deformation of a lopolith.

Stratigraphy and Petrography

Figure 3 presents a composite stratigraphic section for the Agnew Lake Intrusion. It consists of a Marginal, Lower and Upper Series which correlate, as illustrated, with the Lower, Main and Upper Series of the East Bull Lake Intrusion. Mafic mineralogy is replaced by calcic-amphiboles formed during lower amphibolite facies, Penokean-age metamorphism. Compositions of plagioclase cores commonly appear to be near original magmatic values. Primary igneous textures are preserved, but less clearly than in the East Bull Lake Intrusion.

MARGINAL SERIES

The Marginal Gabbronorite Zone (unit 1, *see* Figures 3 and 7a) is characterized by a massive, medium-grained, commonly olivine-normative, gabbronorite. It occurs as units up to 200 m thick with chilled outer contacts against the footwall and encloses large *in situ* remnants of granitic footwall. Sills or dikes, 1 to 20 m thick with chilled margins, commonly occur at the intrusion contact, and may be related to young dike sequences that transect the entire intrusion.

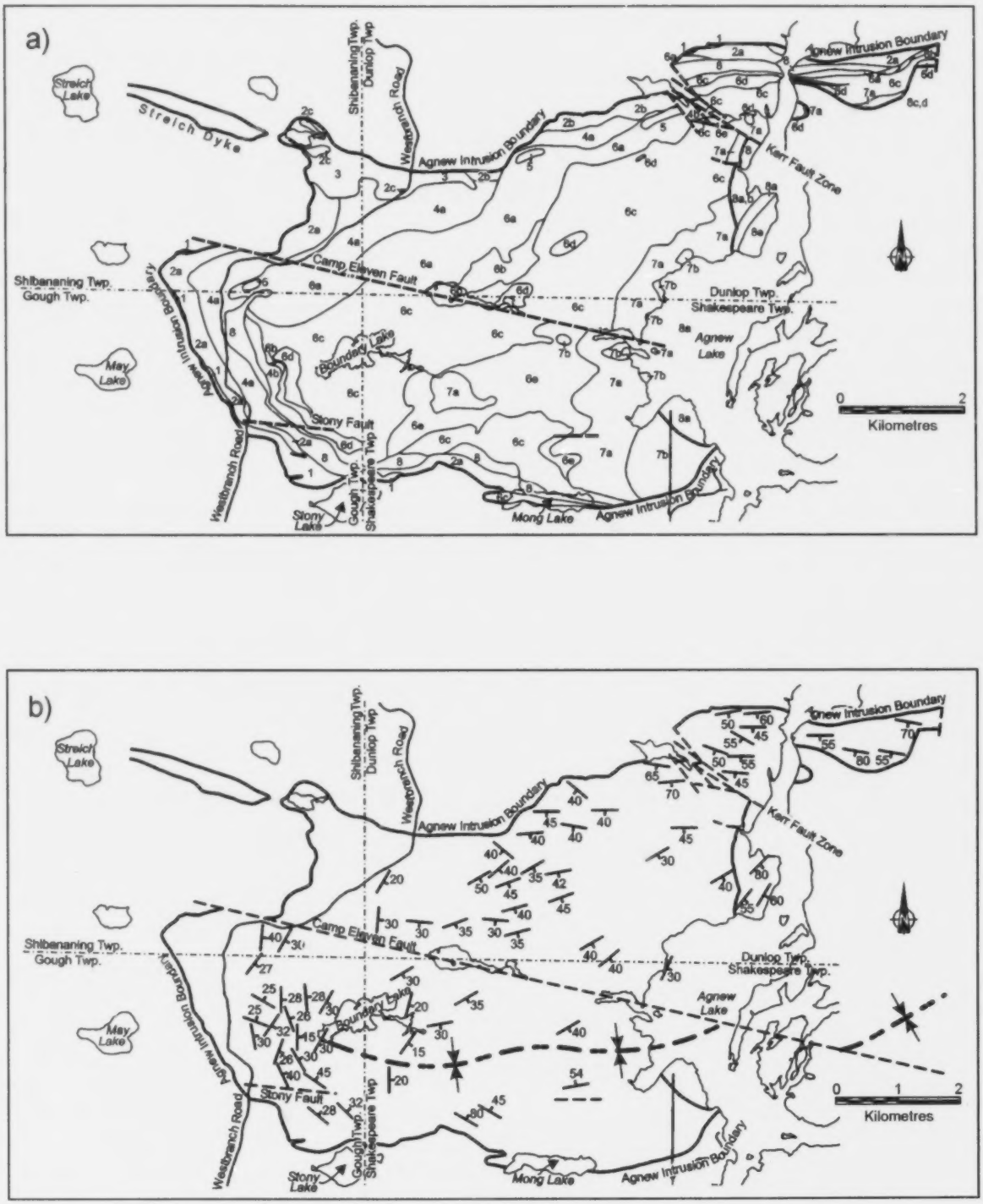

Figure 7. Geology of the Agnew Lake Intrusion. **a)** Geologic map showing main stratigraphic units; unit numbers correspond to those in Figure 3 and in the text. **b)** Structural map showing attitude of centimetre- and metre-scale layering. The strike and plunge of the axial plane of the synclinal, lopolithic structure is the same as that in the Huronian Supergroup supracrustal rocks on the east side of Agnew Lake. Both figures modified from Vogel (1996).

The Marginal Leucogabbronorite Zone (unit 2, *see* Figures 3 and 7a) averages 200 m thick and occurs along most margins of the intrusion, where it either overlies the younger, Marginal Gabbronorite Zone or is in direct contact with the footwall. It consists of 3 distinctive units, namely, the Varitextured, Mottled and Nodular units.

The *Varitextured Unit* occurs in the west and south margins of the intrusion, where it is dominated by leucocratic gabbronorites; mafic layers or lenses are common as are felsic differentiates. Grain size is highly varied on a centimetre-scale, from medium-grained to pegmatitic. These rocks are very similar to varitextured gabbronorite pods in the Anorthosite Zone in the East Bull Lake Intrusion.

The equivalent, or somewhat younger, unit in the north-central margin of the Agnew Lake Intrusion is the *Mottled Unit,* which is characterized by large amphibole oikocrysts (after pyroxene) in a plagioclase-rich matrix. As with the Varitextured Unit, smaller but significant gabbronorite, melanogabbronorite and anorthosite also occur. Layering in the Mottled Unit is irregular and discontinuous. Of great significance in both units is the presence of centimetre- to metre-scale inclusions and pods of melanogabbronorite, footwall granite and, rarely, massive quartz where the unit is adjacent to the footwall. Disseminated PGE-rich chalcopyrite and pyrrhotite are common in the inclusion-bearing parts.

The *Nodular Unit* forms large lens-like areas in the northwest part of the intrusion. It is distinguished by the dominance (70 to 90 modal percent) of 6 cm diameter, well-sorted and closely packed plagioclase nodules in a coarse-grained amphibolitized pyroxenitic matrix. Disseminated PGE-bearing sulphide minerals sporadically occur in the matrix. Whole-rock Mg-number indicates this unit is the most fractionated of the Marginal Series. All of the units in this series have significant proportions of rock with normative olivine in the 1 to 10% range and supporting textural evidence for the presence of modal olivine. Plagioclase core compositions range from An_{77} to An_{32}.

LOWER SERIES

The base of this series is the Inclusion-Bearing Gabbronorite Zone (unit 3, *see* Figures 3 and 7a). The zone is about 180 m thick and hosts footwall and cognate xenoliths; associated copper-nickel-PGE mineralization; and is limited in outcrop to the northwest margin of the Agnew Lake Intrusion where it leads to the Streich dike. Inclusions of Marginal Series rocks are common—especially of the Nodular Unit—in a gabbronorite matrix (An_{79-52}). Similar rocks form the Inclusion-Bearing Zone at the base of the Lower Series in the eastern lobe of the East Bull Lake Intrusion (Chubb 1994). The overlying 350 to 400 m of the Lower Series is represented by the Lower Gabbronorite Zone, consisting of a Massive (4a) and a Lower Layered Unit (4b) (Photo 4), that are separated by a younger conformable phase of the Dendrite Unit (8) (Photo 5). The Massive Unit consists of massive, medium- to coarse-grained gabbronorite and leucogabbronorite (An_{79-61}) and rare melanocratic inclusions. Unit 4b (*see* Figures 3 and 7a) is a layered (centimetre- to metre-scale), medium- to coarse-grained gabbronorite or leucogabbronorite (An_{65-53}). Rocks in both units are commonly olivine-normative. These 2 units are similar to rocks in the Anorthosite and Rhythmically Layered zones, respectively, in the East Bull Lake Intrusion. Dendrite Unit rocks are coarse-grained to pegmatitic gabbronorites, commonly weakly layered, and typically varitextured, with a diagnostic feature being the common occurrence of delicate, branching, pyroxene crystals several centimetres long with interstitial plagioclase, titanomagnetite and granophyre. This unit also occurs higher in the stratigraphy and formed from a more evolved magma than its host rocks.

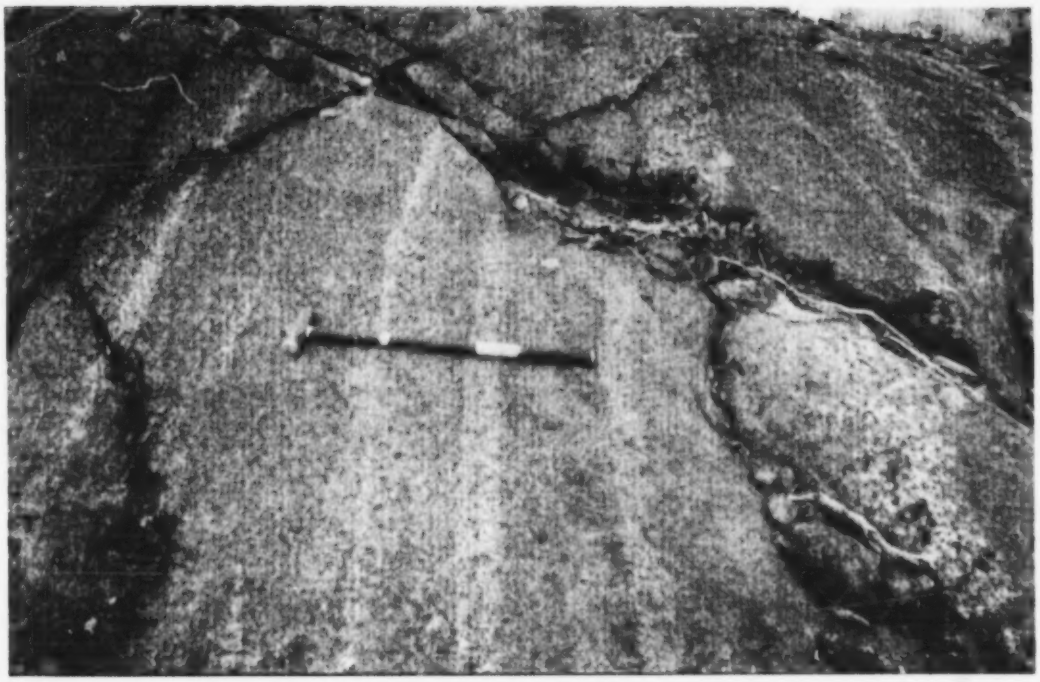

Photo 4. Centimetre- to decametre-scale igneous layering within rocks of the Agnew Lake Intrusion.

Photo 5. Dendrite texture developed with the Lower Gabbronorite Zone of the Agnew Lake Intrusion. Compare with Photo 3a and 3b. Similar rocks will be observed at Stop 7, Day 2.

UPPER SERIES

Most of the rocks in this series have not been recognized in other intrusions of the East Bull Lake intrusive suite; either they were never deposited or they were eroded away. The Olivine Gabbronorite Zone (unit 5, *see* Figures 3 and 7a) is notably more mafic than other units in the Agnew Lake Intrusion. It consists of centimetre- to metre-scale, layered olivine gabbronorite and leucogabbronorite. Disseminated sulphide minerals are common and PGE contents can be as high as those present in the inclusion-bearing rocks in the Marginal and Lower Series. Similar strata, 50 to 60 m thick, occur at the same stratigraphic level in the East Bull Lake Intrusion.

The Upper Gabbronorite Zone (units 6a to 6e, *see* Figure 3) forms about 1000 m of the stratigraphy of the Agnew Lake Intrusion. Vogel, James and Keays (1998) and Vogel et al. (1999) divided it into 5 units. Olivine is absent from rocks in the Upper Gabbronorite Zone. Plagioclase and orthopyroxene are the primocryst (cumulate) phases, with plagioclase compositions being mostly in the range An_{65-40}. The upper Layered (6a) and Mixed units (6b) underlie the Porphyritic Unit (6c), which forms the main mass of this part of the stratigraphy (*see* Figures 3 and 7a). The Porphyritic Unit is a dominantly quartz-normative rock unit characterized by varied amounts of plagioclase phenocrysts and glomerophenocrysts set in a gabbronorite matrix. Diffuse, macrorhythmic, decametre-scale layering of plagioclase-phyric leucogabbronorite and nonporphyritic gabbronorite is typical of this unit.

The Fe-Ti Oxide Zone (units 7a and 7b, *see* Figure 3) forms the upper 200 to 400 m of the Agnew Lake Intrusion; its base is marked by the first appearance of titanomagnetite primocrysts. Primary igneous plagioclase is totally altered in this zone and magmatic textures are very poorly preserved. The Leucogabbro Unit (unit 7a, *see* Figure 3) forms the lower part of this zone. It consists of massive, coarse-grained leucogabbro (normative clinopyroxene greater than orthopyroxene) that has a distinctive clotty texture as a result of metamorphic biotite growth around altered primocryst titanomagnetite. Metamorphic garnet occurs sporadically in these iron-rich rocks. Of particular interest is the presence of disseminated sulphide minerals (with anomalous PGE), most commonly at the top of the unit. The basal contact of the overlying Ferrosyenite Unit (unit 7b, *see* Figure 3) is not exposed, but has been drilled by New Millenium Minerals Corporation (which became Platinum Group Metals Limited in October 2001 as the result of a merger). In this unit, ferrosyenite grades upward into alkali feldspar granite. The ferrosyenite consists of relatively scarce phenocrysts of albite (An_3) and as much as 25 modal percent primocryst magnetite in a recrystallized feldspar-quartz matrix. The magnetite-rich phase of this unit is steel-grey, massive and fine grained. The overlying granite is a white, recrystallized quartz-feldspar assemblage with less than 5% magnetite. Normative calculations suggest that the igneous assemblage had as much as 30% potassium feldspar.

Geochemistry

A comprehensive geochemical database for the Agnew Lake Intrusion can be extracted from Vogel (1996) and a representative suite is presented in Vogel et al. (1999). Representative analyses for units from the Upper Series (not represented in the East Bull Lake Intrusion) and the Streich dike are presented in Table 4. The latter is an estimate of the parent magma composition for all units in the intrusion except for the Olivine Gabbronorite Zone (*see* Figures 3 and 7a). As with the East Bull Lake Intrusion, it is a high-Al, low-Ti, tholeiitic composition.

Rocks in the Marginal and Lower Series of the Agnew Lake Intrusion (except for unit 8, the Dendrite Unit) are olivine-normative. Olivine leucogabbronorite compositions dominate in the Marginal Series (Mg-number 65-76), whereas olivine gabbronorite is dominant in the Lower Series (Mg-number

55-74). In the lower two-thirds of the Upper Series, gabbronorite and their leucocratic equivalents (Mg-number 63-31) dominate. Ferrogabbro, ferrosyenite, and alkali granite compositions (Mg-number 46-12) characterize the Fe-Ti- Oxide Zone. Detailed stratigraphic studies in the Marginal and Lower Series show that these rocks formed in an open system where frequent magma pulses produced a rather monotonous sequence of mafic rocks with thin irregular intervals of fractionated material (Vogel 1996). Pearce-element ratio plots in Figures 4a and 4b show that the main chemical variation is due to plagioclase and olivine for the Marginal Series, and plagioclase, olivine and orthopyroxene for the Lower Series. All units in the Agnew Lake Intrusion show flat heavy rare earth element (HREE) patterns (10 to 40 times chondrite) and light REE enrichment (6 to 100 times chondrite for La) (*see* Figure 5b). REE element concentrations for the Marginal (unit 2) and Lower Series (units 3, 4a, 4b) are the most primitive of the suite (*see* Figure 5b). Both show positive Eu anomalies and both are more primitive in composition than the Streich dike parent magma composition.

Vogel et al. (1999) illustrated, using incompatible elements such as Y, Zr, and Nb, that rocks from the Upper Series of the Agnew Lake Intrusion ultimately fractionate to form iron-rich differentiates, namely, the Fe-Ti Oxide Zone of associated ferrogabbros and oxide-rich ferrosyenites. There is no physical or geochemical evidence that these differentiates are due to magmatic assimilation of country rock. Rather, this part of the intrusion, at least in its upper portion, has apparently become a closed system, i.e., Skaergaard-like in terms of magmatic process (McBirney 1996). Pearce-element ratio diagrams (*see* Figure 4) and petrography indicate that plagioclase and orthopyroxene are the major phases that account for the chemical variation of rocks in the Upper Gabbronorite Zone. REE data for this zone (unit 6c) are consistent with it being less primitive than the underlying Marginal and Lower Series rocks (*see* Figure 5b). Rocks in the Leucogabbro subzone (unit 7a) near the top of the stratigraphy are classified as iron-rich gabbronorites by Vogel (1996). Here titanomagnetite ± clinopyroxene join plagioclase and replace orthopyroxene as the dominant mafic phases. Titanium is not a conserved element in rocks of the Fe-Ti Oxide Zone; consequently, as seen in Figure 4b, rocks from this zone are distinct from all previously described units, and their trend can not be ascribed to fractionation by a specific phase or phases. The REE pattern for this subzone (*see* Figure 5b) mimics the previous patterns but has substantially higher total REEs, consistent with these rocks being comagmatic with the underlying part of the Upper Series. In the Ferrosyenite subzone (unit 7b) at the roof of the intrusion, titanium is not conserved in the Pearce-element ratio plots. The trend of the data for these rocks extends from near the origin parallel to the Al/Ti axis, reflecting the varied proportion of alkali feldspar in these calcium-poor rocks. The slope of the data in Figure 5b for this subzone, and their increased total REE abundance is consistent with it being a fractionated part of the intrusive sequence. The negative Eu anomaly is due to the absence of plagioclase.

Although rocks of the Olivine Gabbronorite Zone occur in the central part of the Agnew Lake Intrusion stratigraphy (*see* Figure 3), the trend they define in the Pearce-element ratio plot (*see* Figure 4a) shows that they are, on average, more mafic than strata above and below. Their trend intersects that defined by the rest of the rocks in the Agnew Lake Intrusion near the estimated parent magma composition (Streich dike) indicating that the 2 groups are comagmatic. These data are consistent with previously discussed mineralogical data. In Figure 5b, the REE pattern for rocks from the Olivine Gabbronorite Zone has a slope that is similar to other Agnew Lake Intrusion rocks, supporting the comagmatic nature of the 2 groups. The low total REE abundance is indicative of the relatively primitive and mafic character of this zone.

Mineralization

Finely disseminated and erratically distributed, blebby (up to 3 cm in diameter) chalcopyrite and pyrrhotite, with minor to trace pentlandite, in modal amounts from 0.5 to 2.0%, typically characterize

mineralized localities in the Agnew Lake Intrusion. Typically Cu is greater than Ni and combined Cu+Ni is approximately 1 to 1.5 wt %. In a high proportion of sulphide-rich samples, values of Pt+Pd = 0.5 to 3.0 g/t are not uncommon and values as high as 10 g/t do occur, with Pd/Pt typically 1 to 3 (data from Assessment File Reports filed by BP Resources Canada Limited, Resident Geologist's office, Sudbury). Although there is often a positive correlation between PGE, Cu and total sulphide contents, some of the highest PGE samples have less than 100 ppm S.

As with the East Bull Lake Intrusion, the greatest sulphide mineralization and highest PGE values have been found in inclusion-bearing units, with the sulphide minerals normally occurring in the matrix. Mineralization occurs in the Marginal Leucogabbronorite Zone at the stratigraphic base of the Agnew Lake Intrusion, specifically along its west margin. The varitextured Leucogabbronorite unit (unit 2a, *see* Figure 7a) is highly prospective within 50 to 100 m of the contact, as is the Mottled Leucogabbronorite (unit 2b) along the north margin of the body. The rocks that host this mineralization are very similar in mineralogy, texture and stratigraphic position to those that host sulphide mineralization in the Anorthosite Zone in the western East Bull Lake Intrusion (i.e., Moon Lake area). Mineralized, fragment-rich rocks also occur in the Inclusion-Bearing Gabbronorite Zone (unit 3, *see* Figures 3 and 7a), which forms the lowest subdivision of the Lower Series. The mineralogy and textural distribution of the silicate and sulphide mineral phases is the same as in the Marginal Series. These inclusion-bearing rocks intrude units of the Marginal Series, in particular the Nodular Unit, and clearly represent a major phase of magma injection into the magma chamber. The similarity in rock types, mineralization and field relationships with those at the east and west ends of the eastern lobe of the East Bull Lake Intrusion, suggest that the Lower Series, Inclusion-Bearing Zone, in the Agnew Lake Intrusion is correlative with the Lower Series, Inclusion-Beaing zone, in the East Bull Lake Intrusion (*see* Figure 3).

A third significant mineralized zone occurs near the top of the intrusion in the uppermost part of the Leucogabbro subzone and immediately below the Ferrosyenite subzone (*see* Figure 3). The mineralization was predicted to be present by Vogel (1996), forming as a result of closed-system fractionation of a sulphur-undersaturated, PGE-rich magma. This type of occurrence is characterized by disseminated chalcopyrite and pyrrhotite, in amounts of 1 to 2 modal percent, that increase in abundance toward the contact with the overlying Ferrosyenite subzone. Mapping and trenching by New Millenium Minerals Corporation has identified several occurrences of this type of mineralization near this contact along the eastern side of Agnew Lake.

A fourth environment merits mention although mineralization has yet to be recognized. The Olivine Gabbronorite Zone at the base of the Upper Series is believed to represent an influx of primitive magma (Mg-number ~70) into a chamber dominated by fractionated liquids (Mg-number ~55). Thus, the opportunity may have existed for the formation of reef-type mineralization due to magma mixing. This idea is supported by the presence of Pt+Pd values as high as 0.5 to 1.0 g/t in rocks of the same type and stratigraphic level in the East Bull Lake Intrusion (Peck et al. 2001).

Vogel (1996) analyzed 22 barren samples from the Agnew Lake Intrusion, sampling all stratigraphic units shown in Figure 3. Since the PGEs partition strongly into sulphide liquid, their abundance in a silicate rock is an excellent indicator of the status of sulphur-saturation of the magma from which the sample crystallized (Hamlyn and Keays 1986; Vogel and Keays 1997). In the barren samples, Pt varies from 0.7 to 62 ppb, with most samples in the 10 to 30 ppb range; and Pd varies from 0.2 to 58 ppb, with most samples ranging from 10 to 40 ppb. These data mimic those for the East Bull Lake Intrusion (Peck et al. 1995) and are very similar to most, non-reef, silicate mineral assemblages from the Lower, Critical and lower Main Zones of the Bushveld Complex (Barnes and Maier 1999). When plotted against stratigraphic position, Pt and Pd data show peaks:

1. at the base of the Marginal Series
2. at the base of the Inclusion-Bearing Zone, Lower Series

3. near the estimated position of the Olivine Gabbronorite Zone, and

4. at the base and the top of the Leucogabbro subzone near the roof of the intrusion.

All correspond to areas of known or suspected mineralization.

Mantle-normalized PGE distribution for barren rocks from the Agnew Lake Intrusion is similar to that for rocks of the East Bull Lake Intrusion. The Pt-Pd-Au-Cu part of the figure is elevated (1 to 10 times mantle abundance except for Au) relative to the Ni-Ir-Ru part (<0.01 to 0.5 times mantle values) (James et al. 2002a).

The anomalous PGE concentrations, together with typically very low sulphur contents (≤150 ppm), of barren samples from the Agnew Lake Intrusion indicate that the main mass of Agnew Lake Intrusion magma did not experience sulphide saturation prior to emplacement into the chamber. All samples plot in the sulphur-undersaturated area in the Cu-Pd diagram of Vogel and Keays (1997). Peach, Mathez and Keays (1990) estimated that saturation for mantle-derived magmas is about 800 ppm, well above what is observed in these rocks. Peck et al. (2001) argue that contact-type mineralization in the Marginal and Lower Series of the East Bull Lake Intrusion formed from magmas that were sulphur-saturated prior to intrusion. Mineralization was further upgraded in PGE content by prolonged high temperature mixing of very small volumes of sulphide phases with high volumes of silicate liquid upon entering the magma chamber. The complex, chaotic, varitextured nature of the rocks that host mineralization in the Marginal and Lower Series of the Agnew Lake Intrusion, and the evidence that the magma system was "open" during formation of this part of the intrusion is consistent with the model of Peck et al. (2001). The mechanism to explain mineralization near the roof of the intrusion, i.e., sulphide saturation due to fractionation in a closed system, is also consistent with a PGE-rich, sulphur-undersaturated, parent magma. It also allows for the possibility of reef-type mineralization at the base of the Upper Series due to magma mixing between the sulphur-undersaturated, parent magma and the sulphur-saturated, fractionated magma present within the evolving magma chamber (e.g., the Olivine Gabbronorite Zone, unit 5, *see* Figure 3.)

ROAD LOG, DAY 2, AGNEW LAKE INTRUSION

Note: Most of the roads used during day 2 are used regularly by logging trucks. Consequently, extreme caution should be taken when parking vehicles on the shoulder and when examining outcrops during day 2.

Geological map reference: Vogel (1996), Card and Palonen (1976).

0.0 km	Start at the junction of Highway 69S and the Highway 17W bypass. Set odometer to zero. Head west on Highway 17 to Massey.
0.4 km	Junction of Highway 17W bypass and Regional Road 80 (Long Lake Road). Continue west on Highway 17 bypass.
70.9 km	Junction of Highway 17 and 6, just north of Espanola. Continue west on Highway 17.
76.4 km	Junction of Highway 17 and Agnew Lake Lodge Road on the west side of the hamlet of Webbwood. Turn right (north), and follow Agnew Lake Lodge Road north to the intersection with West Branch Road.
82.4 km	Turn left onto West Branch Road and drive north for 17.0 km to the intersection with Power Line Road.

99.4 km Junction between West Branch Road and Power Line Road, turn left and drive west on Power Line Road.

100.8 km Junction between Power Line Road and Quarry Road. Park vehicles and walk south and west from junction onto a large outcrop.

Stop 1. Inclusion-Bearing Unit

UTM 4226691E, 5137144N. This outcrop is within the Inclusion-Bearing unit, which occurs at the base of the Lower Gabbronorite Zone (Unit 3, Vogel (1996) map, outcrop #153). On the west side of this outcrop the Inclusion-Bearing unit is in contact with the rocks of the Neoarchean Ramsay–Algoma gneiss complex. This stop shows the following features.

1. Overall the unit consists of metre-scale, pod-like autoliths of nodular anorthosite and pyroxenite in a medium grained, massive leucogabbronorite to melagabbronorite matrix (Photo 6). The outcrop is cut by plagioclase-phyric Matachewan diabase dikes with chilled margins. The dikes strike 340°, and exhibit fractures and veins that trend 250° and which show sinstral displacement.

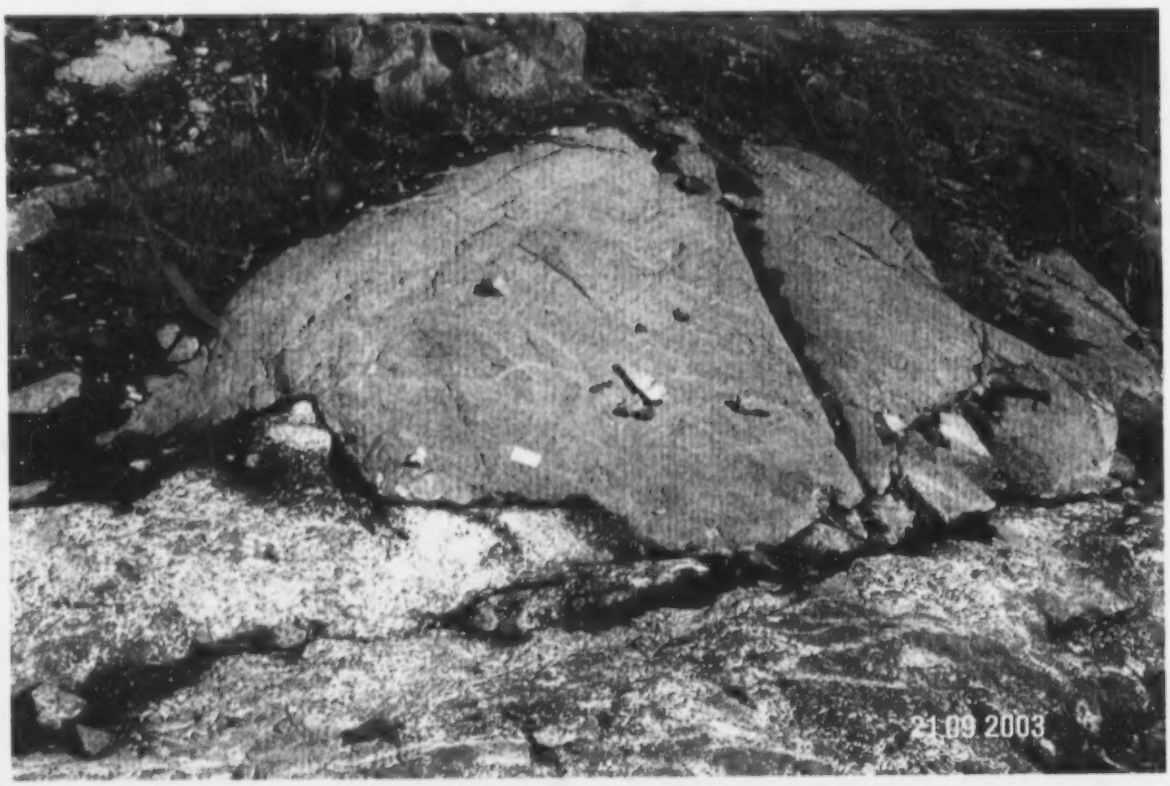

Photo 6. Stop 1, Day 2. Large pyroxenite pod in centre of photograph is hosted by rocks of the Inclusion-Bearing unit, shown in the foreground, which at this locality are hosted in a predominantly leucogabbronoritic matrix. Scale card near contact between the pod and the leucogabbronorite is 8.5 cm long.

2. PGE concentration for disseminated chalcopyrite-pyrrhotite-pentlandite mineralization averages 107 ppb Pd+Pt based on 723 analyses; the range is 1 to 1873 ppb, Pd/Pt = 2.3 and Cu/Ni = 2.1.
3. In part of the outcrop, pyroxenite (assemblage blue-green hornblende+quartz+magnetite in one sample) occurs as discontinuous lenses, or pods, that are 30 to 40 m in length and 5 m in width, strike 290° (*see* Photo 6), and which contain trace disseminated copper-nickel-PGE mineralization.
4. Assay data for the pyroxenite pod shown in Photo 6. Sample 154547, at the edge of pyroxenite pod has Pd+Pt = 264 ppb, Pd/Pt = 4.6, Ni+Cu = 969ppm, Cu/Ni = 4.2, S = 1800 ppm. Sample 154533 has Pd+Pt = 37 ppb, Pd/Pt = 1.5; Cu+Ni = 220 ppm, Cu/Ni = 1.3, S = 200ppm. Samples 154607 and 154739, middle of pyroxenite pod, have PGE at or below detection limits.
5. Granitic xenoliths are common in the Inclusion-Bearing unit at the contact between the intrusion and the older granitic gneisses at the west margin of the outcrop.

Return to the Power Line Road and walk north for about 200 m along the Quarry Road to Stop 2.

Stop 2. Nodular Anorthosite Unit, Marginal Leucogabbronorite Zone

The quarry outcrop (Photo 7a) is an excellent example of the Nodular unit, the youngest unit of the Marginal Leucogabbronorite Zone, Agnew Lake Intrusion (Unit 2c, Vogel (1996) map, outcrop #126). This is the only area of the intrusion where this unit is observed and its age relationship relative to the previous outcrop area is clear as it occurs as autoliths in the Inclusion-Bearing unit. It occurs in a similar stratigraphic and marginal position at the east margin and the central narrow part of the East Bull Lake Intrusion (Nodular Anorthosite unit, Anorthosite Zone; Chubb, Hannila and Peck (1994)). At this locality the principal rock type is a very coarse-grained, nodular, glomeroporphyritic anorthosite (Photo 7b). It consists of glomerophenocrysts of plagioclase (1 to 14 cm in diameter) that form 80 to 90% of the rock and interstitial altered pyroxene. One to 3% disseminated chalcopyrite and pyrrhotite occur in the matrix to the nodules. Peck et al. (1995, Appendix 5, Part A) reported Pd+Pt in the range 35 to 470 ppb, Pd>Pt, Cu+Ni = 244 to 2138 ppm and Cu>Ni from similar sulphide mineral-bearing rocks from the East Bull Lake Intrusion. Chubb et al. (1995) suggested that the nodules formed due to elevated degrees of undercooling within dike-like constrictions at the margin of the intrusion. Nodule formation may have resulted from feldspar growth on pre-existing plagioclase phenocrysts to form primary nodules, followed by agglomeration processes forming larger secondary and tertiary nodules. Northwest-trending plagioclase-phyric Matachewan diabase dikes intrude the Nodular unit in this outcrop (*see* Photo 7a). UTM 426718E, 5137364N.

Return along the Quarry Road for about 30 m and walk onto the outcrop immediately east of the road.

Stop 3. Inclusion-Bearing Unit, Lower Gabbronorite Zone

In walking from Stop 2 to Stop 3 you have traversed into the Inclusion-Bearing unit of the Lower Gabbronorite Zone (Vogel (1996) map, outcrops #192 to 195). The main phase of the Inclusion-Bearing unit consists of metre-scale zones or autoliths of nodular anorthosite enclosed in a coarse-grained matrix

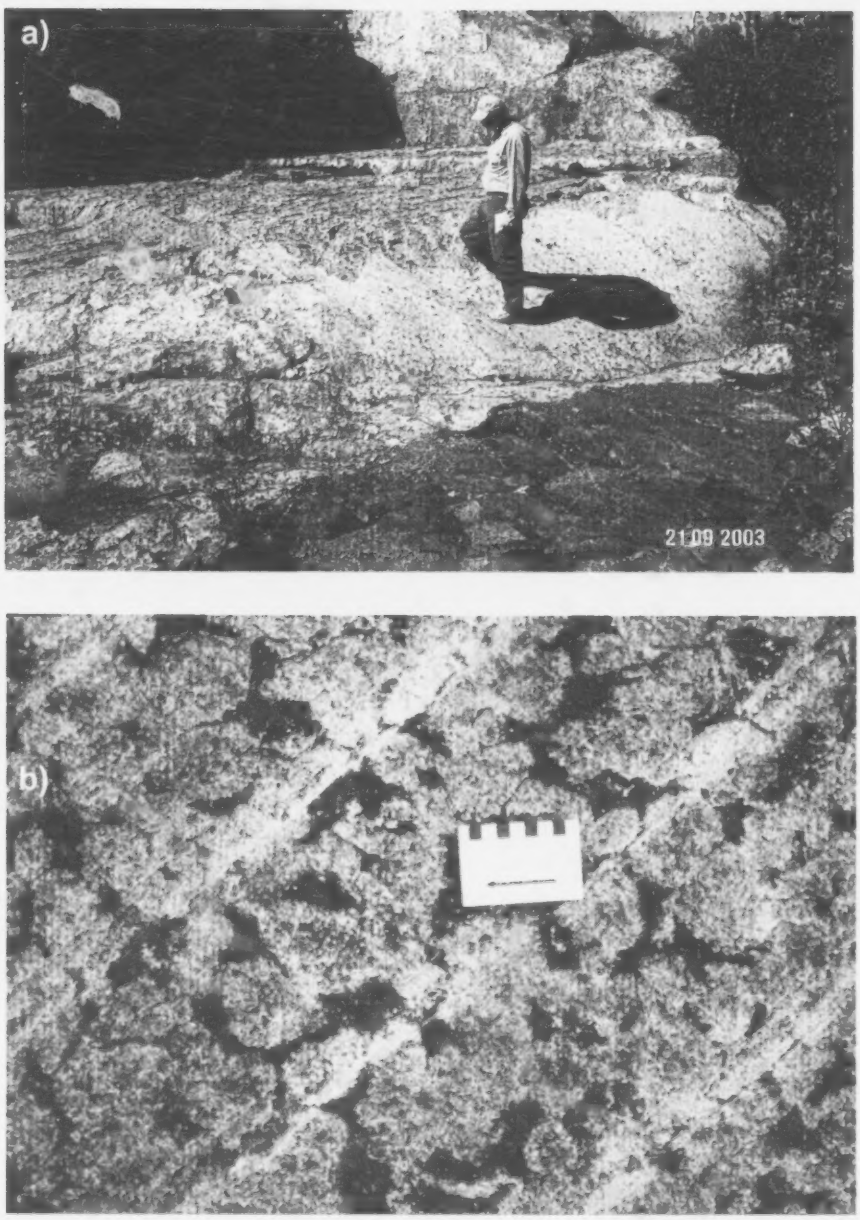

Photo 7. Stop 2, Day 2. **a)** Stone quarry in Nodular Anorthosite unit. Author R.S. James is standing on nodular anorthosite; dark rocks in foreground belong to a Matachewan swarm diabase dike that intrudes the Nodular Anorthosite unit. **b)** Close-up of nodular anorthosite, showing closely packed plagioclase glomerophenocrysts with minor interstitial, altered, pyroxene. Scale card is 8.5 cm long.

of gabbronorite to leucogabbronorite. Two several metre-wide Matachewan diabase dikes, striking 290°, intrude the unit. A younger, Mesoproterozoic, 10 to 20 cm wide Sudbury swarm diabase dike (~1240 Ma) strikes 300° and intrudes all rock units. The Sudbury dike has narrow chilled margins, cooling fractures perpendicular to its margin, and contains trace disseminated sulphide minerals. It also contains small pyroxenitic and granitic xenoliths, and weathers a rusty brown colour, in contrast to the older Matachewan swarm dikes. At this locality Pd+Pt are as high as 2155 ppb and average 178 ppb (based on 154 analyses), with Pd/Pt = 3.1 and Cu/Ni = 1.4. UTM 426870E, 5137333N. Return to vehicles, and head east from the Quarry Road–Power Line Road junction. Reset odometer to zero.

0.2 km Park by side of road and walk to outcrop beside the road. (Vogel (1996) map, outcrop #215.)

Stop 4. Inclusion-Bearing Unit, Lower Gabbronorite Zone

This is an additional stripped outcrop area illustrating the Inclusion-Bearing unit. It contains autoliths of pyroxenite and nodular anorthosite in a matrix of leuco- to melagabbronorite (Photo 8). Disseminated sulphide minerals occur in the matrix assemblage and not in the autoliths and range from 1 to 5 modal percent. Assay values for this mineralization are Pd+Pt average 180 ppb (based on 451 analyses), ranging from 2 to 2012 ppb, with Pd/Pt = 3.1 and Cu/Ni = 1.5. Note the 2 to 5 cm wide plagioclase-phyric dike that is locally choked with euhedral plagioclase phenocrysts where the dike width narrows (Photo 9). UTM 427074E, 5137348N. Return to vehicles and head east on Power Line Road.

0.6 km Park by side of road and examine outcrop on the north side of the road (Vogel (1996) map, outcrops #216 and 217).

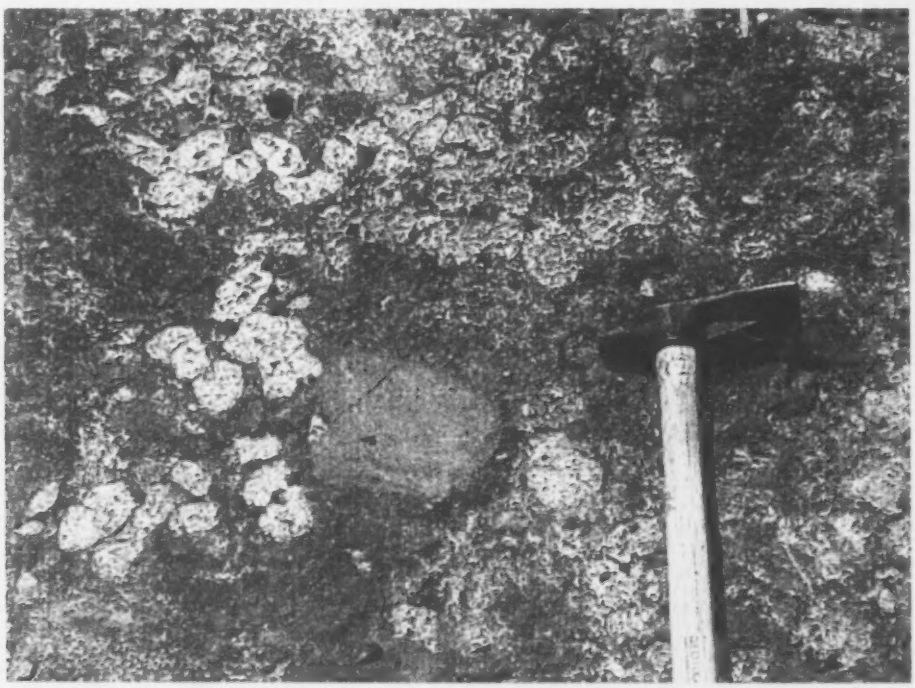

Photo 8. Nodular anorthosite from the Inclusion-Bearing Gabbronorite Zone, Lower Series, of the Agnew Lake Intrusion, roughly 200 m south of the nodular anorthosite quarry, in the vicinity of Stop 4, Day 2. Note the pyroxenite fragment in the centre of the photograph.

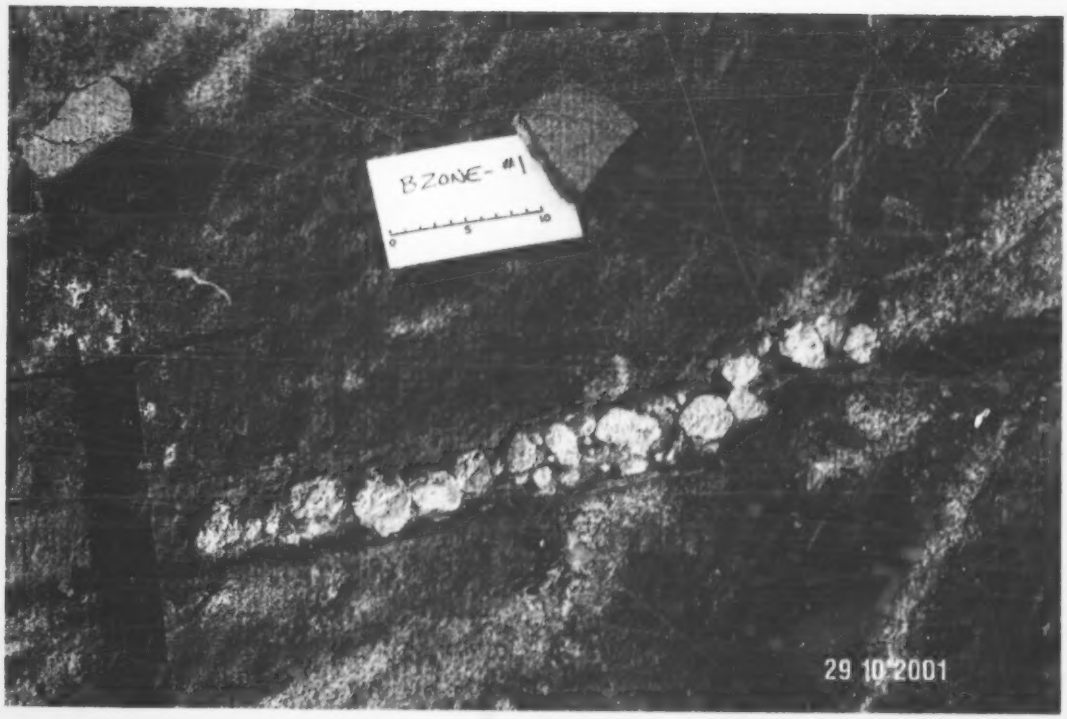

Photo 9. Diabase dike containing large, rounded plagioclase crystals, similar to the nodules of the Nodular Anorthosite unit, cutting across rocks of the Inclusion-Bearing Gabbronorite Zone, Lower Series, of the Agnew Lake Intrusion.

Stop 5. Sudbury-Type Breccia

In this outcrop, Sudbury-type breccia cuts through a Matachewan diabase dike that strikes 230°. The dike intruded rocks of the Ramsay–Algoma gneiss complex. The breccia consists of xenoliths of plagioclase, diabase, and granitic material, ranging from millimetre- to centimetre-sized, in a foliated, fine-grained matrix that, in part, has a distinctive flow-like fabric. Chubb et al. (1995) provide detailed descriptions of several similar dikes and argue that they represent pseudotachlyte that formed as a result of the Sudbury impact event at 1850 Ma. UTM 427504E, 5137368N.

Return to vehicles and head east on Power Line Road.

1.4 km	Junction with West Branch Road, turn right and head south on West Branch Road.
7.1 km	Pull over and park vehicles, examine outcrops on both sides of the road (Unit 2a, Vogel (1996) map, outcrops #326 (east) and #329 (west side of road)).

Stop 6. Varitextured Unit, Marginal Leucogabbronorite Zone

This outcrop lies within the Varitextured Unit of the Marginal Leucogabbronorite Zone, Marginal Series. Both outcrop areas (AZ 1 – east side of road, and AZ 2 – west side of road) consist dominantly of gabbronorite to melagabbronorite and minor leucogabbronorite. Inclusions of pyroxenite and scarce nodular anorthosite are scattered throughout the matrix assemblage, indicating that at least part of the

outcrop area may belong to the Inclusion-Bearing unit. Disseminated sulphide mineralization occurs mainly in the gabbronorite matrix. Over 200 analyses from the 2 outcrop areas average 232 ppb Pd+Pt with individual analyses as high as 2375 ppb; Pd/Pt is about 2 as is Cu/Ni. Later quartz veins strike at 220° and are offset by fractures and/or faults that strike 290°. UTM 425257E, 5133932N.

Return to vehicles and continue south on West Branch Road.

8.0 km Junction with logging road. Turn left (east) and drive east on the logging road for ~200 m to red flagging on road side, located at UTM 425917E, 5133294N. Follow the flagged line through bush, walking north at about 334° for approximately 440 m. On the route, you will cross Gridline 3-5, 275E of Pacific North West Capital Corporation. **This traverse should not be made alone, and should be only conducted using appropriate footwear and field equipment.**

Stop 7. Dendrite Unit, Lower Gabbronorite Zone

UTM 425744E, 5133665N. The outcrop is the bottom of a cliff face that shows extensive excellent exposure of the dendritic unit of the Lower Gabbronorite Zone. This unit is recognized as a distinct stratigraphic unit in the Agnew Lake Intrusion where it is well-exposed along the west and southwest margin of the plateau area that forms the central part of the intrusion. The textures and mineralogy are the same as observed the previous day at East Bull Lake Intrusion (Stop 7, Day 1), but here the dendritic texture is much more extensively developed. The texture occurs either as large irregular masses, sometimes almost layer-like, or as pod-like zones, particularly where this unit is gradational into the overlying layered gabbronorites. At this locality the dendritic habit of the altered pyroxenes can be rapidly replaced by coarse-grained gabbroic pegmatite assemblages, so that the rocks become quite varitextured. Examine the outcrop at the base of the cliff face and then work your way up the ridge, all the time observing the variation in rock types or the lack of variation.

Having climbed the cliff face we will traverse east through the Dendritic Unit and into the overlying Layered unit of the Lower Gabbronorite Zone. In doing so we are walking through outcrop #333 into #334 (Vogel (1996) map). At the top of the cliff face (in outcrop #333) the dendritic gabbronorite is more typically restricted to local pod-like areas and enclosed in a coarse-grained to almost pegmatitic gabbroic rock. In the western part of outcrop #334 metre-scale isomodal phase layering is present, identical in general features to that observed in the East Bull Lake Intrusion. At this locality it dips approximately 30° to the east. Locally, pods of dendritic gabbronorite are observed in the Layered unit. The stratigraphic units that overlie the Layered unit to the east exhibit decametre or thicker scale layering. As a result, shallow dipping surfaces consisting of individual layers form extensive outcrops of apparently only one rock type.

Return to the vehicles by walking southward (~160°) across the top of the plateau to intersect the logging road, then follow the road southwest to the parked vehicles at the base of the plateau.

This ends Day 2. Retrace route to West Branch Road, Agnew Lake Lodge Road, and Highway 17.

RIVER VALLEY INTRUSION, OVERVIEW

Country Rocks, Structure and Geometry

The River Valley intrusion is located about 65 km east-northeast of Sudbury (*see* Figure 1) near the community of River Valley. The intrusion underlies parts of Crerar, Dana, Henry, Janes, McWilliams and Pardo townships, but is best exposed in Dana Township, where it locally contains well preserved primary mineralogy and textures (Hrominchuk 1999, 2000; Easton and Hrominchuk 1999, 2001a, 2001b; Easton 2001, 2003). Although recently mapped (Easton and Hrominchuk 1999, 2001a, 2001b; Easton 2003; Easton and terMeer 2004; Hrominchuk 1999, 2000), studies of the stratigraphy, geochemistry and mineralization present within the River Valley intrusion are limited in comparison to similar studies on the East Bull Lake and Agnew Lake intrusions.

Of all the East Bull Lake intrusive suite bodies studied to date, the River Valley intrusion exhibits the clearest relationships with other members of the Paleoproterozoic rifting suite described earlier. It is cut by mafic dikes geochemically correlated with the Matachewan and Hearst dike swarms, as well as by felsic intrusive rocks coeval with the Huronian Supergroup metavolcanic rocks (Easton and Hrominchuk 1999, 2001b). Furthermore, in Street Township, granitic rocks dated at 2460±20 Ma, contain inclusions of East Bull Lake intrusive suite leucogabbroic and anorthositic rocks (Easton and Murphy 2002). Easton (2003) has reported similar inclusions in granitic plutons in Henry and Loughrin townships. Unfortunately, the relationship between the River Valley intrusion and the Huronian Supergroup is obscured by tectonism along the Grenville Front.

Along the Grenville Front, the River Valley intrusion is either in thrust contact with quartzite of the Mississagi Formation (Davidson 1986) or is in an unknown contact relationship with mafic and felsic metavolcanic rocks of the lower Huronian Supergroup (Easton and Hrominchuk 1999). On the basis of geochemical correlation, however, these metavolcanic rocks are likely ~2460 Ma in age (Easton and Hrominchuk 1999), and consequently, most likely were deposited after emplacement of the River Valley intrusion. The River Valley intrusion is also cut by olivine diabase dikes of the 1238 Ma Sudbury dike swarm (Easton 2000) and the Grenville dike swarm (590 Ma).

Intrusive contacts between the River Valley intrusion and the Archean basement are exposed throughout the eastern half of the intrusion, and are generally sharp. Zones of intense diking, equivalent to the Border Zone in the East Bull Lake Intrusion, have not been observed. In fact, in both Dana and Crerar townships, Archean para- and orthogneisses adjacent to the intrusion are devoid of any mafic dikes, apart from a few Matachewan–Hearst swarm diabase dikes. In some parts of Dana Township, a fine- to medium-grained gabbro is present at the contact, and may represent a chilled facies of the intrusion. In many areas, however, an inclusion and/or fragment-bearing facies occurs proximal to the contact, making it difficult to ascertain the true extent and significance of this finer grained facies.

As in the case of the East Bull Lake Intrusion, a "syenite" (actually an alkali feldspar granite) body in Dana Township was originally interpreted as a felsic differentiate of the River Valley intrusion (e.g., Card and Lumbers 1975). On the basis of contact relationships and geochemistry, Easton (2000) interpreted it as Archean in age, an interpretation that has been recently confirmed by U/Pb zircon dating, which yielded a preliminary age of ~2660 Ma (Easton and Kamo 2003).

Previous maps of the River Valley intrusion (e.g., Lumbers 1973; Card and Lumbers 1975) indicated that the intrusion extended west into Henry and Loughrin townships as a series of "tails" surrounded by gneissic country rocks. This map pattern was interpreted to be the result of either

1. a pattern of complex interference folding during Penokean and Grenvillian orogenesis, or
2. a system of feeders to the main body of the intrusion located in Crerar and Dana townships.

Furthermore, it was also speculated that other isolated bodies of East Bull Lake intrusive suite rocks in the Grenville Province, west of the River Valley intrusion (e.g., Red Deer Lake, Street Twp., southern Wanapitei complex, Table 1), represented parts of the River Valley intrusion now isolated from the main mass through erosion and tectonism. Work conducted by Easton (2003) suggests otherwise. East Bull Lake intrusive suite rocks west of Crerar Township are different in form, stratigraphy, and composition, and are intruded into distinctively different country rocks than those found in the River Valley intrusion. Consequently, East Bull Lake intrusive suite rocks located west of Crerar Township likely represent part of one or more intrusions that were emplaced separately from the River Valley intrusion.

STRUCTURAL STATE AND DEGREE OF PRESERVATION

Figure 8 outlines the general structural state of the River Valley intrusion and its country rocks in Dana and Crerar townships, as well as the degree of textural preservation within the intrusion and the country rocks. Six main preservation regimes can be recognized, which are described by Easton (2003), these form the basis of the divisions shown in Figure 8.

The Sturgeon River, and the Neoproterozoic to early Paleozoic fault that extends along it, is an important structural feature within the River Valley intrusion (*see* Figure 8). North of the Sturgeon River, the River Valley intrusion contains large areas of preserved or partly preserved primary mineralogy. Deformation is concentrated along discrete shear zones, both vertical and subhorizontal, that cut the intrusion (Easton and Hrominchuk 1999, 2001b; Hrominchuk 2000). Grenvillian deformation is largely concentrated near the Grenville Front, along the west side of the intrusion (*see* Figure 8). North of the Sturgeon River, Grenvillian metamorphism results in the incipient development of corona textures in rocks of the River Valley intrusion and the Sudbury diabase dike swarm, with metamorphic conditions estimated at 5 to 7 kb and 625°C (Tettelaar 2000; Easton and Hrominchuk 1999). An empirical observation is that rocks of leucogabbroic composition are most commonly recrystallized, whereas orthopyroxene-bearing rocks are generally more resistant to metamorphic recrystallization. The geometry of the intrusion north of the Sturgeon River appears to be largely sheet-like, with igneous layering generally dipping shallowly (20 to 30°) to the south and southeast. This has resulted in exposure of the basal contact (margin or sidewall?) of the River Valley intrusion for 8 to 10 km along its north and east margins, providing an extensive target area for mineral exploration.

In contrast, south of the Sturgeon River, pockets of preserved mineralogy and texture (Photo 10) are less abundant, occurring mainly in eastern Crerar Township (*see* Figure 8). Igneous layering at several scales is preserved within this area of the intrusion (Photo 11) (Easton 2003). Where present, igneous layering dips moderately (40° to 60°), and stratigraphy is apparently folded (Easton and Hrominchuk 2001a). This folding results in a variety of trends for the basal, mineralized contact of the intrusion, making mineral exploration more difficult than in the north. Penetrative fabrics of Grenvillian-age are common (Photo 12), with much of the River Valley intrusion consisting of gneissic rocks of gabbroic and leucogabbroic composition. Grenvillian metamorphic effects result in more complete development of corona textures in rocks of both the River Valley intrusion and the Sudbury diabase dike swarm in Crerar Township, with metamorphic conditions estimated at 7 to 9 kb and 650°C (Tettelaar 2000; Easton and Hrominchuk 1999).

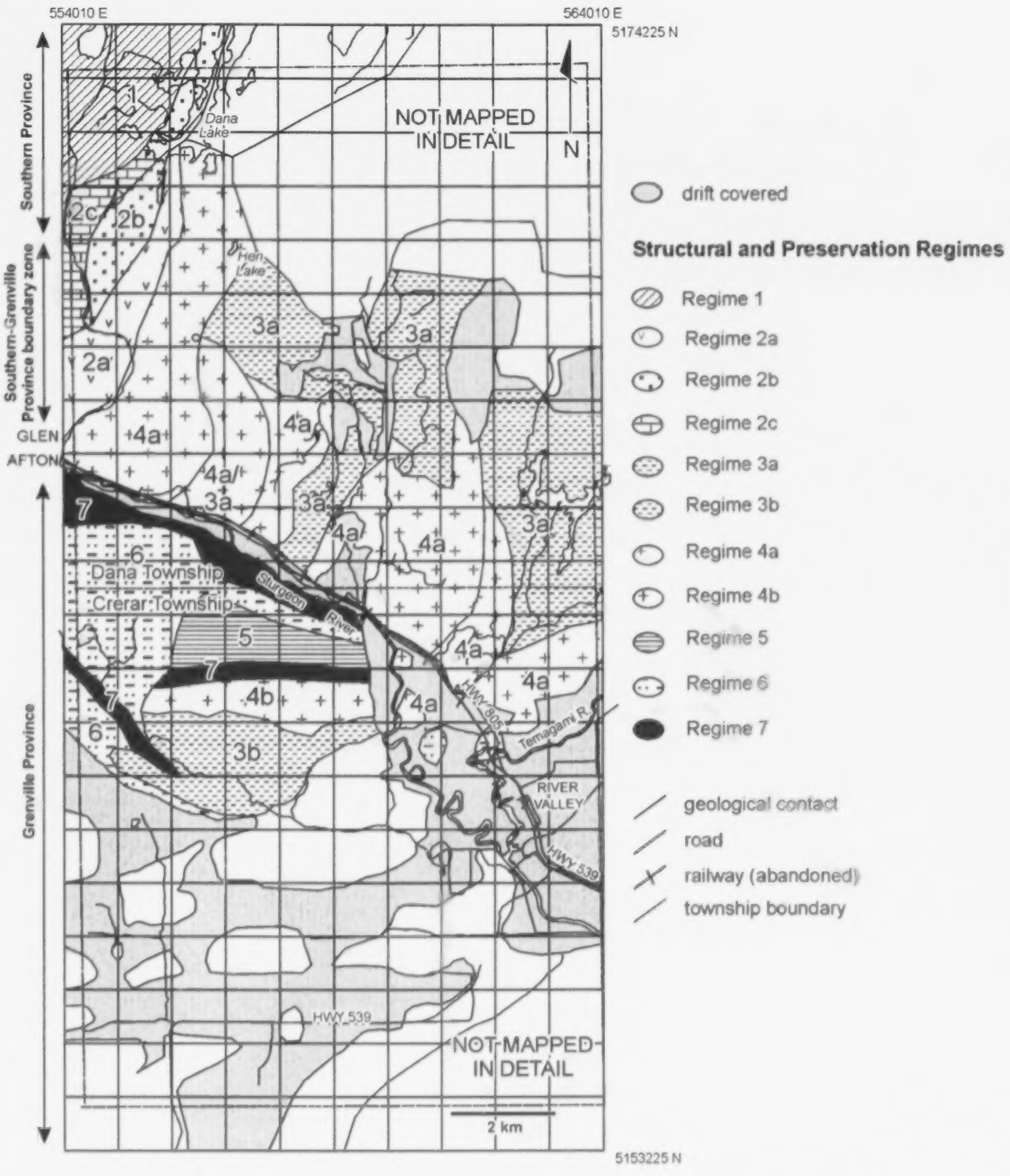

Figure 8. Map showing the degree of primary textural preservation within rocks of Crerar and Dana townships (*from* Easton 2003).

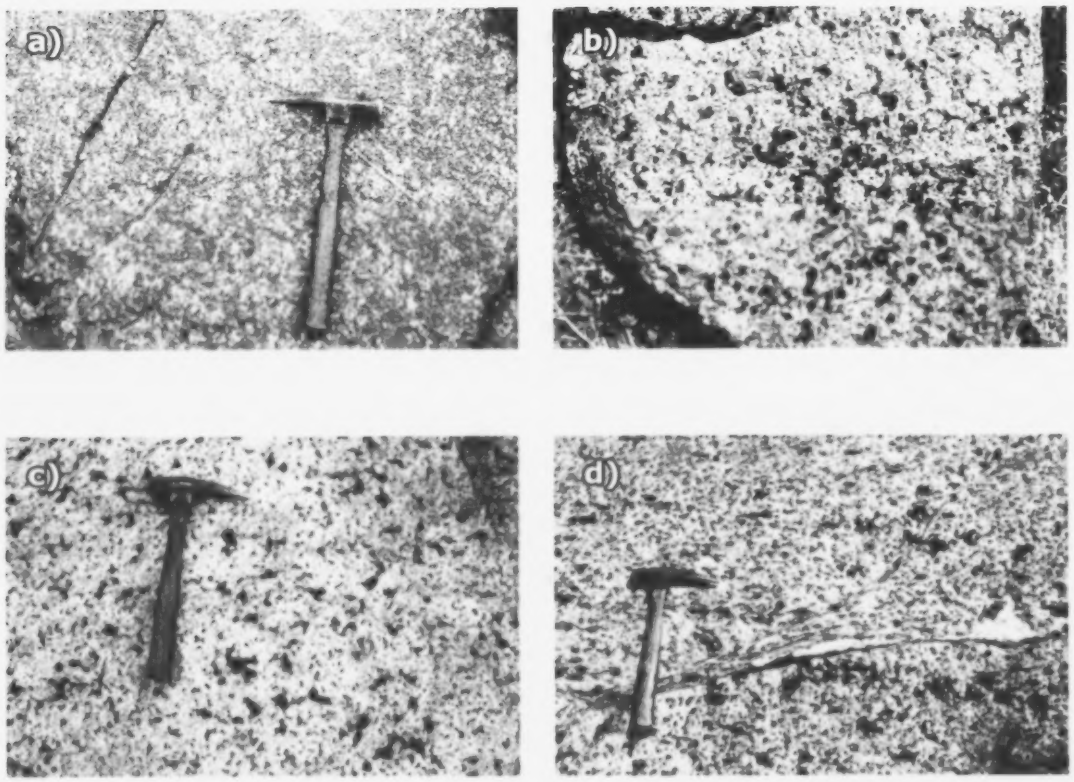

Photo 10. Progressive textural changes. **a)** Igneous-texture in medium-grained norite from leucogabbronorite zone of the River Valley intrusion, Crerar Township. Note dark colour of feldspars. UTM 556115E 5171466N. **b)** Partly recrystallized rock of the River Valley intrusion, preserving igneous-texture in medium-grained gabbronorite from leucogabbronorite zone of the River Valley intrusion, Crerar Township. Mafic minerals have thick, green-weathering amphibole coronas rimming dark orthopyroxene grains. UTM 556886E 5161009N. **c)** Recrystallized but massive leucogabbronorite from leucogabbronorite zone of the River Valley intrusion, Crerar Township. This rock no longer preserves primary mineralogy, but is relatively undeformed. Note white colour of feldspars, and lack of well defined crystal shapes. Mafic mineral clots are aggregates of fine-grained amphibole. UTM 557400E 5160225N. **d)** Typical undeformed but recrystallized leucogabbronorite from the Positano Quarry, East Bull Lake intrusive suite, Loughrin Township. UTM 547000E 5160600N. Hammer handle in all photos is 30 cm long.

CONTACTS

Copper, nickel and platinum group element exploration in the River Valley intrusion has focussed on its contacts, as outlined by Lumbers (1973). This is only an effective exploration tool if the contacts of the intrusion are primary and not tectonic. Easton (2003) noted 3 main contact types that are present between the River Valley intrusion and other rock units in the map area:

1. preserved intrusive contacts,
2. deformed and disrupted intrusive contacts, and
3. wholly tectonic (fault) contacts.

Near the northwest edge of Dana Township, the western contact of the intrusion is tectonic, as originally described by Davidson (1986). The northern and eastern contacts of the intrusion are primary, although they are locally cut, with minimal lateral offset, by mylonite of the Southern–Grenville province boundary zone. Mineralization in northwestern Dana Township (Dana North and South zones of Pacific North West Capital Corporation) is spatially associated with preserved intrusive contacts. Much of the

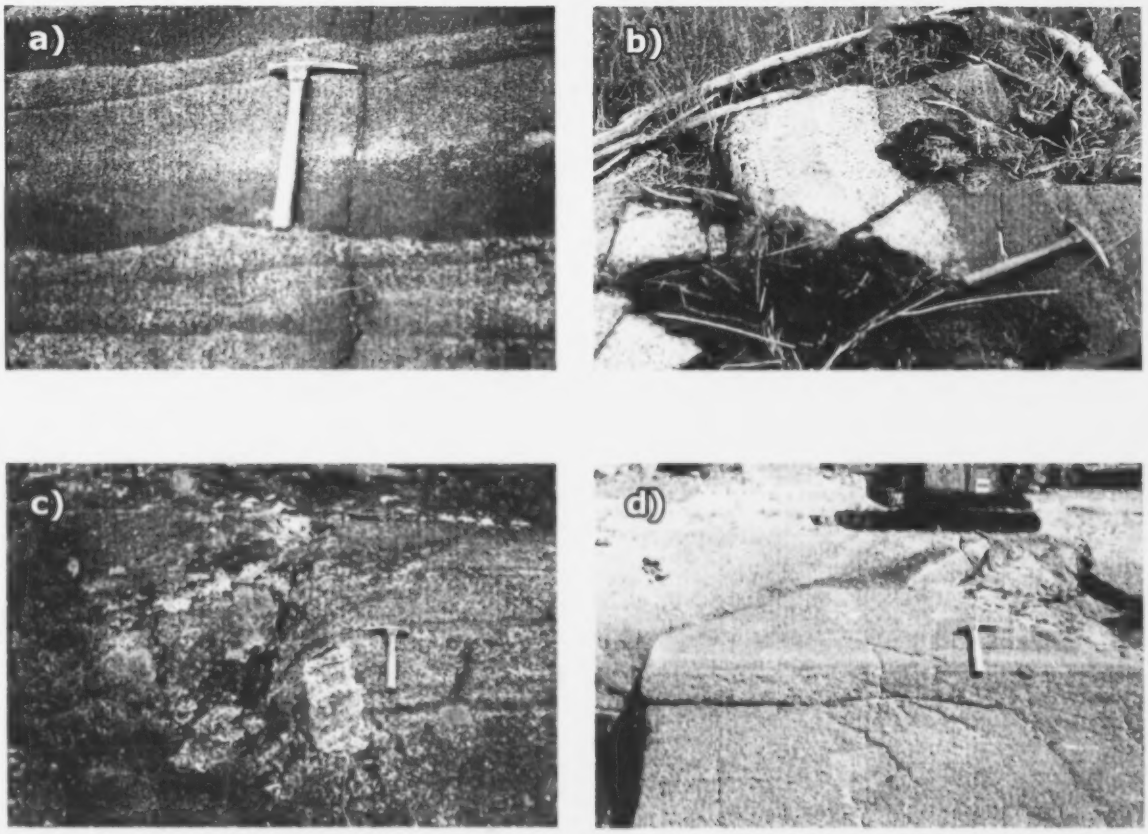

Photo 11. a) Igneous layering within the norite zone, River Valley intrusion, Crerar Township. UTM 556769E 5159980N. **b)** Igneous layering within the River Valley intrusion in Crerar Township, near the top of the anorthosite zone and the base of the olivine gabbronorite zone. Dark layers are melanorites, some of which are olivine-bearing. UTM 557390E 5160360N. **c)** Layering within leucogabbronoritic rocks immediately above the heterogeneous basal zone of River Valley intrusion, Crerar Township. UTM 557585E 5159590N. **d)** Large-scale igneous layering within leucogabbronoritic rocks of the River Valley intrusion exposed in the Dana Quarry, Dana Township. UTM 558630E 5165385N. Hammer handle in all photos is 30 cm long.

northern contact of the intrusion in Dana Township is likely primary, and both the Lismer's Ridge and Azen Creek zones occur near this contact. It should be noted that based on surface exposure, the Azen Creek zone is apparently located near, but not at the contact. Recent drilling by Pacific North West Capital Corporation has shown that the contact in the Azen Creek zone dips generally shallowly to the south and in fact the Azen Creek zone is proximal to the contact – the difference is that the mineralization is hosted in "inclusion-bearing" or fragment-bearing units rather than the breccias observed in the Dana North area. Also, recent drilling at Jackson's Flats shows the contact is oriented in a northwest direction and is steeply dipping, with mineralization occurring in fragment-bearing units rather than "breccia", much like the situation at the Azen Creek zone. In Crerar Township, a primary intrusive contact is preserved in the area that includes the Tomrose occurrence, and Crerar 2 to 4. To date, most of the mineralization identified in Crerar Township lies near this contact.

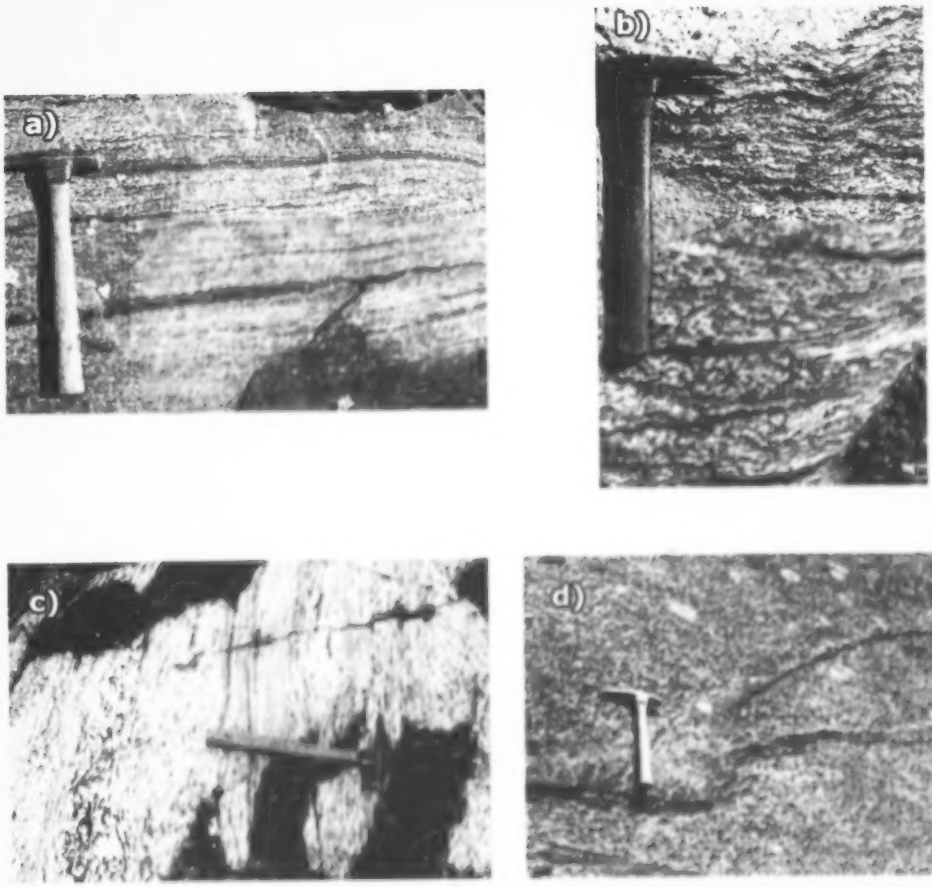

Photo 12. a) Typical leucogabbroic gneiss of an East Bull Lake intrusive suite intrusion in Henry and Loughrin townships. Note the lack of a prominent leucosome phase. UTM 548443E 5159789N. **b)** Protomylonitic to mylonitic textures present in a high-strain zone in the River Valley intrusion, Crerar Township. UTM 559751E 5163890N. **c)** Strain gradient within rocks of the River Valley intrusion, northern Crerar Township. Foliated to gneissic leucogabbro on top, straight and irregularly layered gneiss on bottom. UTM 557225E 5162512N. **d)** Epidote-clot developed just right of the hammer handle in leucogabbro gneiss of the River Valley intrusion, Crerar Township. Such epidote clots are common in gneissic leucogabbro throughout the study area. UTM 555495E 5163580N. Hammer handle in all photos is 30 cm long.

In contrast, most of the southern contact of the intrusion in Crerar Township, although poorly exposed, is a major shear zone, which is discordant to internal contacts in the intrusion. It is likely that the eastern contact of the River Valley intrusion north of the Sturgeon River, is also a tectonic contact.

Examples of tectonized intrusive contacts may be present in 3 areas.

1. The western contact of the intrusion along Highway 805, particularly in the southern half of Dana Township. However, it is possible that this contact represents an upper, rather than a basal, contact of the intrusion.
2. The other 2 examples occur in Crerar Township, but represent areas where zones of mafic straight gneisses are in contact with other highly deformed gneisses or different units within the intrusion. Similar rocks occur just south of Glen Afton, south of the Sturgeon River; however, to date no mineralization has been reported from the latter area.

Hrominchuk (1999, 2000) recognized 2 types of mafic rock associations near areas of primary contacts. These are a marginal zone and an inclusion-bearing zone. There is considerable variation in thickness of both these zones along the primary contacts of the intrusion, ranging from 50 m thick to almost 500 m thick in the Dana North area. To date, mineralized zones along the contact occur where these units are relatively thick (e.g., Dana North, Varley, Azen, Tomrose).

Stratigraphy and Petrography

Although historically referred to as an anorthosite to anorthositic gabbro intrusion, the River Valley intrusion is dominated (~60% of surface area) by gabbro, norite, gabbronorite, leucogabbronorite and leuconorite, with some units containing modal olivine. True anorthosite makes up less than 10% of the surface area of the intrusion, but even in these areas, the distribution of mafic minerals is irregular, so that the areas of anorthositic rock are closer to noritic anorthosite or gabbroic anorthosite in composition. Noritic and gabbroic anorthosite probably underlie about 30% of the surface area of the intrusion. Observed stratigraphy in the intrusion differs north and south of the Sturgeon River.

NORTH OF THE STURGEON RIVER

Low regional dip and poor exposure in key areas in Dana Township has hampered stratigraphic analysis, despite the textural and mineralogical preservation of the rocks. Despite these difficulties, Hrominchuk (2000), as presented in Figure 9, developed an interpretive stratigraphic section for the River Valley intrusion located north of the Sturgeon River. The intrusion north of the Sturgeon River has been subdivided into 5 zones (Hrominchuk 2000; James et al. 2002a), as follows:

1. Marginal zone
2. Inclusion and/or Fragment-Bearing zone
3. layered Olivine Gabbronorite zone
4. Layered Gabbronorite zone, and
5. massive, locally varitextured, Leucogabbronorite zone.

Marginal Zone

The Marginal zone is characterized by a fine- to medium-grained, black plagioclase-phyric, quartz-phenocryst-bearing, gabbronorite that is partly chilled and is typically strongly mineralized at the contact with granitic plutonic and gneissic rocks. This contact is commonly sheared and normally consists of a complex chaotic mixture of footwall blocks and fine- to medium-grained gabbronoritic rocks. Because rocks immediately adjacent to the contact usually contain large blocks and screens of footwall material, exact definition of the contact in some areas is problematic. The Marginal zone consists mostly of medium-grained norite to gabbronorite and is typically well preserved. In thin section, the rock consists of dark-brown to tan cumulate (An_{79} core; An_{74} rim) to intercumulate (An_{68}) plagioclase, woody-brown cumulate orthopyroxene (En_{44-76}), interstitial clinopyroxene, with accessory magnetite, quartz, biotite, sulphide minerals, and calcic myrmekite. Fragments are commonly quartzofeldspathic gneiss, alkali-feldspar granite and amphibolite gneiss. Granitic fragments contain quartz with a small amount of alkali feldspar and biotite or amphibole. Quartzofeldspathic gneiss fragments commonly have a preserved gneissic texture and are mostly quartz with a small amount of biotite. Amphibolite gneiss fragments are a fine-grained, commonly foliated, matte of blue-green amphibole and epidote group minerals.

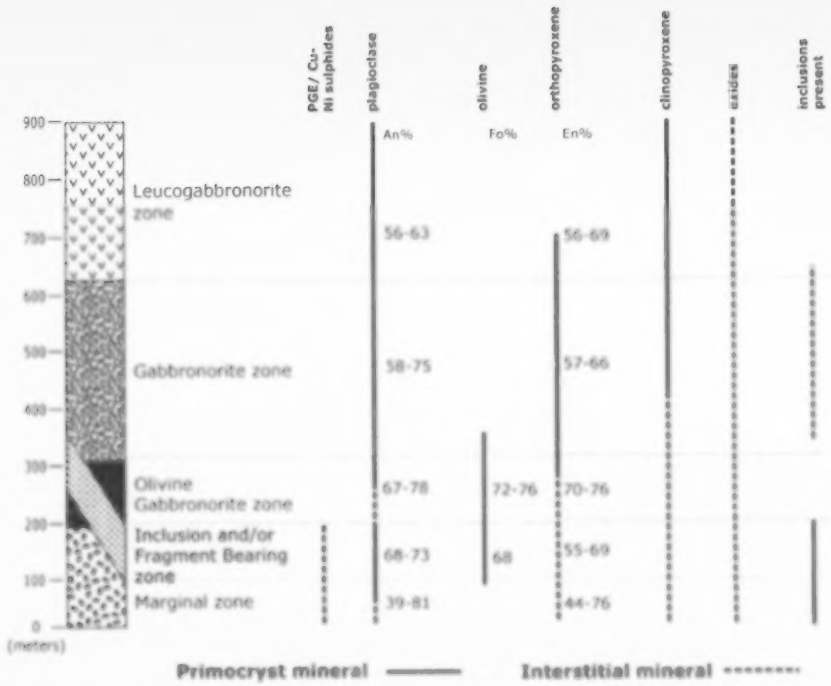

Figure 9. Interpreted stratigraphic sequence and distribution of primary mineral phases and compositions within the River Valley intrusion north of the Sturgeon River. *From* Easton (2003).

Inclusion and/or Fragment-Bearing Zone

This zone is commonly in gradational contact with the underlying Marginal zone, but its appearance is marked by a sharp increase in the size and amount of felsic fragments and the appearance of compositionally and texturally varied mafic to ultramafic inclusions or xenoliths. Inclusions consist of 3 main types: alkali feldspar granite and other granitic rocks, amphibolite, and olivine-rich rocks (troctolites, peridotites). Granitic, gneissic and amphibolite fragments are similar to those described above for the Marginal zone, but they are commonly surrounded by pods or lenses of a very coarse-grained to pegmatitic assemblage of biotite, muscovite, amphibole, plagioclase, quartz and alkali feldspar (Hrominchuk 2000). It is important to note, however, that in all of the mineralized areas explored by Pacific North West Capital Corporation to date, there have been less than 1% exotic fragments in the Breccia and Inclusion-Bearing units, which is their equivalent to this zone. Autoliths are abundant (typically up to 90%) and locally (e.g., outcrop scale) may constitute up to 100% of the rock. Troctolite or peridotite autoliths are similar in all respects to the olivine norite to melatroctolite and peridotite from the Olivine Gabbronorite zone described below; most are olivine-bearing gabbronorite to peridotite in composition, with subordinate leucogabbronorite. They are usually well rounded and weakly to very strongly mineralized. The host matrix to the autoliths and fragments is typically a fine- to medium-grained, green to black gabbro or olivine-bearing gabbro to gabbronorite, often with disseminated to blebby sulphide mineralization.

Olivine Gabbronorite Zone

The Olivine Gabbronorite zone is composed of 0.3 to 1.5 m thick layers that are olivine-rich at the base, and erosive into underlying layers, and which grade upward into olivine gabbronorite or troctolite to slightly more plagioclase-rich end members. Layers are deeply weathered due to the presence of serpentine minerals and fine-grained magnetite after olivine. This zone is well exposed in only a few places, but is normally 50 to 150 m thick, and grades into the overlying, olivine-poor layered Gabbronorite zone. The Olivine Gabbronorite zone contains a wide range of rock types; however, olivine is present in most, with troctolite and olivine norite predominant. Olivine is generally medium- to coarse-grained, Mg-rich (Fo_{72-76}), coronitic, and variably serpentinized. Plagioclase is calcic (An_{72-76}), dark-colored, and inclusion rich. Orthopyroxene (En_{70-76}) occurs in 2 forms, as euhedral woody prisms, and as large (up to 10 cm) oikocrysts enclosing olivine and plagioclase. Clinopyroxene is found only as interstitial anhedral crystals.

Gabbronorite Zone

The Gabbronorite zone is composed of metre-scale, modally layered rocks with a maximum continuous thickness of about 200 m. This represents a minimum stratigraphic thickness, since faults or zones of intense deformation always truncate the top of the section. The unit typically consists of alternating metre-thick layers of norite and gabbronorite (±olivine) and leucogabbronorite. Locally, this unit is very coarse-grained, with zones rich in felsic fragments surrounded by pegmatitic pods containing quartz, epidote, magnetite, alkali feldspar, plagioclase, amphibole, pyroxene, biotite and garnet. The Gabbronorite zone consists of layers that begin as olivine-bearing norite and fractionate to gabbronorite. Coarse-grained black norite dominates; it consists of large (2 cm) orthopyroxene (En_{57-66}) and brown plagioclase (up to 3 cm)(An_{58-75}) primocrysts, interstitial clinopyroxene and inverted pigeonite, and rare olivine. Metamorphosed equivalents contain altered plagioclase, amphiboles (fine-grained actinolite and coarse-grained hornblende), small garnets and quartz.

Leucogabbronorite Zone

This zone consists of non-layered, massive, medium- to coarse-grained rocks ranging in composition from leucogabbronorite to anorthosite. It forms the highest stratigraphic levels of the intrusion (generally the tops of topographic highs) in Dana Township. They are commonly highly deformed or faulted; a complete section of these rocks has not yet been found in Dana Township, however, a more complete section may be present in Crerar Township (Easton and Hrominchuk 1999). These rocks consist mainly of dark plagioclase (An_{56-63}) with subordinate interstitial and primocryst clinopyroxene and inverted pigeonite (En_{56-69}). Where metamorphosed, the more leucocratic rocks form very white-weathering rocks with small pods of amphibole-rich material dispersed throughout.

SOUTH OF THE STURGEON RIVER

As previously noted, establishing a stratigraphic column for the River Valley intrusion has been difficult, despite the state of preservation of the rocks. South of the Sturgeon River, steeper regional dips have made the task somewhat easier; however, the section there may contain more layer-parallel faulting, and units are only well preserved in the southwestern part of the intrusion. Easton and Hrominchuk (1999) originally suggested that a section up to 3.5 km thick could be identified; however, this interpretation assumed that the units were dipping uniformly to the west at roughly 50°, that the section was not folded,

and that there were no layer-parallel faults present. Further analysis indicated that the section was indeed folded (Easton and Hrominchuk 2001a). Unlike the area north of the Sturgeon River, this section has not been formally divided into stratigraphic zones; for reference, however, informal zone names are given in italics to facilitate comparison with the Dana Township section. The Crerar Township section has a maximum thickness of 1.4 km, and from base upward, consists of:

- 150 to 200 m of gabbro and melanogabbro, forming a heterogeneous ***Marginal zone*** that contains fragment-rich zones, disrupted layering, and considerable diking. Sulphide minerals are common in this zone. This zone grades upward into leucogabbro and anorthositic gabbro. This zone corresponds roughly to the Marginal and Inclusion and/or Fragment-Bearing zones present in the intrusion north of the Sturgeon River.
- 400 to 500 m of gabbroic anorthosite to anorthosite (***Anorthosite zone*** and thin ***Olivine Gabbronorite zone***). Melanogabbro and olivine melanogabbronorite layers up to 2 m thick occur near the top of this zone. This zone apparently does not have an equivalent unit north of he Sturgeon River, but a lowermost gabbroic anorthosite to anorthosite is present in most other East Bull Lake suite intrusions (Figure 10). It is possible that the melanocratic layers in the upper part of this zone correspond to the Olivine Gabbronorite zone present north of the Sturgeon River.
- 350 m of norite and gabbronorite (***Gabbronorite zone***), commonly layered on the scale of centimetres to decametres, with layers having pyroxenite bases and gabbroic anorthosite tops (Photo 10b). Layering on the scale of metres to decametres is also inferred to be present in this zone. This zone may be equivalent to the Gabbronorite Zone present north of the Sturgeon River.
- 200 m of leucogabbro to gabbroic anorthosite (***Leucogabbronorite zone***). This zone may be equivalent to the Leucogabbronorite Zone present north of the Sturgeon River.
- 200 m or more of oxide-bearing leucogabbro to gabbroic anorthosite (***Oxide-Bearing Leucogabbronorite zone***). A regional magnetic anomaly is associated with this unit. Rocks within this zone show a marked decrease in Mg-number (less than 50) compared to other stratigraphic units in the River Valley intrusion (typically greater than 57).
- The top of the section is not observed due to intense deformation in the rocks above this stratigraphic level.

The most significant difference between the Dana and Crerar township sections is the presence of a thick unit of leucogabbro to anorthosite between the Marginal zone and the Olivine Gabbronorite and Gabbronorite zones in the Crerar Township section. In one locality, a few outcrops of nodular anorthosite are present near the base of the leucogabbro to anorthosite unit. At another locality, this unit contains a decametre-thick layer of megacrystic anorthosite, with 1 to 5 cm equant, blocky plagioclase crystals partly separated by clotty, coarse-grained and weakly poikilitic, amphibolitized pyroxene. In addition, the varitextured to massive uppermost Oxide-Bearing Leucogabbronorite zone is not observed in Dana Township, and is the only unit that contains both Mg-number and normative An less than 55.

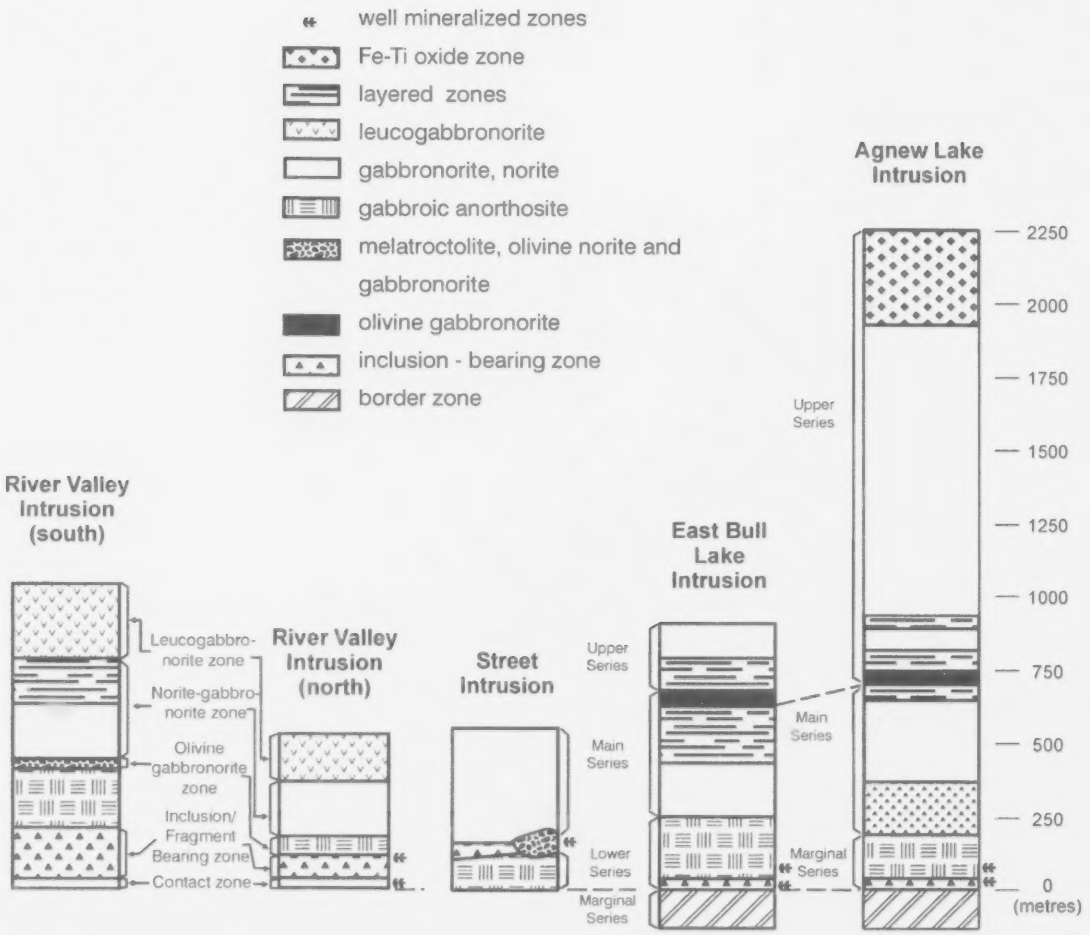

Figure 10. Generalized cross-sections for the Street metagabbro and the River Valley, East Bull Lake and Agnew Lake intrusions of the East Bull Lake intrusive suite. East Bull Lake section *modified from* Peck et al. (1995), Agnew Lake Intrusion section *modified from* Vogel (1996), River Valley data *from* Easton (2003).

STRATIGRAPHIC COMPARISON WITH OTHER EAST BULL LAKE SUITE INTRUSIONS

As shown in Figure 10, the composite stratigraphic section from the best preserved enclave of the River Valley intrusion in Crerar Township contains elements common to both the northern River Valley, the East Bull Lake, and the Agnew Lake intrusions. If the Crerar Township stratigraphy is a true section through the intrusion, then it is similar in thickness to other East Bull Lake intrusions (*see* Table 1). The exception is the Agnew Lake Intrusion (~2.3 km thick), which unlike the other intrusions, includes felsic differentiates near the top. The Crerar Township section also suggests that the River Valley intrusion locally includes an anorthositic zone near the base of the body, similar to most other East Bull Lake intrusions (*see* Figure 10).

Geochemistry

Geochemical data from the intrusion can be found in Easton and Hrominchuk (2002) and Easton (2003). Overall, the chemistry of the rocks are similar to that of other intrusions of the East Bull Lake suite. Silica is generally less than 50 weight percent. Vogel et al. (1999) noted that in the case of the Agnew Lake Intrusion, SiO_2 less than 50 weight percent is characteristic of the stratigraphically lower part of the intrusion. The same effect may be present in the River Valley intrusion, as most of the samples reported to date are from the lower part of the intrusion (below the Oxide-Bearing Leucogabbronorite zone). A few samples, located stratigraphically higher in the River Valley intrusion in Crerar Township show a marked decrease in Mg-number (from typically greater than 57 to less than 43). These rocks are generally of gabbroic anorthosite composition and oxide mineral-bearing.

Representative analyses of each stratigraphic unit present in the River Valley intrusion north of the Sturgeon River are listed in Table 5, as well as in Hrominchuk (2000) and James et al. (2002a). Rocks of the Marginal zone are CIPW quartz-normative; Olivine Gabbronorite zone rocks are olivine-normative, whereas most rocks in the upper units are only silica saturated. Samples from the Marginal zone (*see* Table 5, analyses 1 and 2) show much higher Ti, Fe, K, Na, P, Ba, Zr and Y contents than do most other River Valley intrusion samples. Hrominchuk (2000) interpreted these elemental variations as a possible contamination signature. The high concentration of Ti and Fe in some footwall phases (*see* Table 5, analysis 12), relative to typical River Valley intrusion rocks, is consistent with some of the Ti and Fe contents in sample CZ7-1000 resulting from wall rock assimilation (James et al. 2002a).

The matrix of the Inclusion and/or Fragment-Bearing zone is high in Mg, Ca, Al, and Fe, consistent with its plagioclase, orthopyroxene and olivine-dominated mineralogy. The fragments, inclusions and xenoliths of this zone are extremely varied in composition, partially resorbed, and commonly mineralized. The felsic fragments show similarities to the footwall alkali feldspar granite (James et al. 2002a). Mafic inclusions are similar to the rocks in the lowest part of the layered Olivine Gabbronorite zone. The Olivine Gabbronorite zone is characterized by rocks high in MgO (15 to 24 wt.%) and low in SiO_2 (38 to 45 wt.%), with anomalous Ni contents attributed to the predominance of primocryst olivine (*see* Table 5, analyses 5 and 6). Rocks from the layered Gabbronorite zone show gradual fractionation to more Si-, Al-, Ca-, Na-, K-rich and Mg-poor compositions (*see* Table 5, analysis 9), a trend also observed in the uppermost stratigraphic unit. A sample of magnetite gabbro from the uppermost part of the stratigraphy in Crerar Township (Easton 2003) may be similar to the lowermost ferrogabbros from the Agnew Lake Intrusion, and is the most evolved sample found to date in the River Valley intrusion.

Pearce element ratio diagrams for the River Valley intrusion (James et al. 2002) and detailed petrography indicate that major and trace element trends are controlled by plagioclase, olivine and orthopyroxene, with very little contribution from clinopyroxene (James et al. 2002a). Samples from the Olivine Gabbronorite zone show a variation from olivine + plagioclase near the base to plagioclase + orthopyroxene controlled geochemistry near the top of the zone (James et al. 2002a). Plagioclase is commonly a phenocryst phase within marginal and fine-grained rocks indicating very early crystallization, and most likely quickly joined by olivine as the first cumulate phases. Fractionation and cooling of the magma caused orthopyroxene to replace olivine as a cumulate phase during crystallization of the marginal rocks and the Olivine Gabbronorite zone. This is indicated by orthopyroxene rims on olivine and large orthopyroxene oikocrysts enclosing olivine and plagioclase near the top of this zone (James et al. 2002a). Rocks above this point show trends that indicate fractionation of magma due to plagioclase and orthopyroxene toward more Fe- and alkali-rich compositions.

Chondrite-normalized rare earth element patterns for samples north and south of the Sturgeon River are shown in Figure 11. Most samples show total REE contents and patterns similar to those found in the

East Bull Lake and the Agnew Lake intrusions. In Figure 11, REE patterns for the proposed Dana Township stratigraphy show a slight fractionation trend with stratigraphic height and the influence of cumulate plagioclase (reflected in the magnitude of the negative Eu anomaly). The contaminated contact sample shows significant light REE enrichment over other marginal samples and rocks of all other zones. There are 2 groups of melanocratic rocks (Easton 2003). One with patterns and REE contents similar to other River Valley intrusion rocks; the other with high total REE and La/Yb. This second group has higher normative-orthopyroxene and lower-normative olivine contents than the first. A similar two-fold grouping occurs in the orthopyroxene hornblendite samples, perhaps suggesting a genetic linkage between the River Valley intrusion and these bodies.

A sample of a primitive dike or layer from the Marginal zone exhibits a flat (~10 times chondrite) to slightly U-shaped pattern (*see* Figure 11), and is also characterized by relatively high silica and MgO, and low Ti and alkalis. It may represent a boninite-like parent magma composition for the River Valley intrusion (James et al. 2002a). The significance of such a parental magma has already been discussed in the section "Magma Composition and its Relationship to Mineralization".

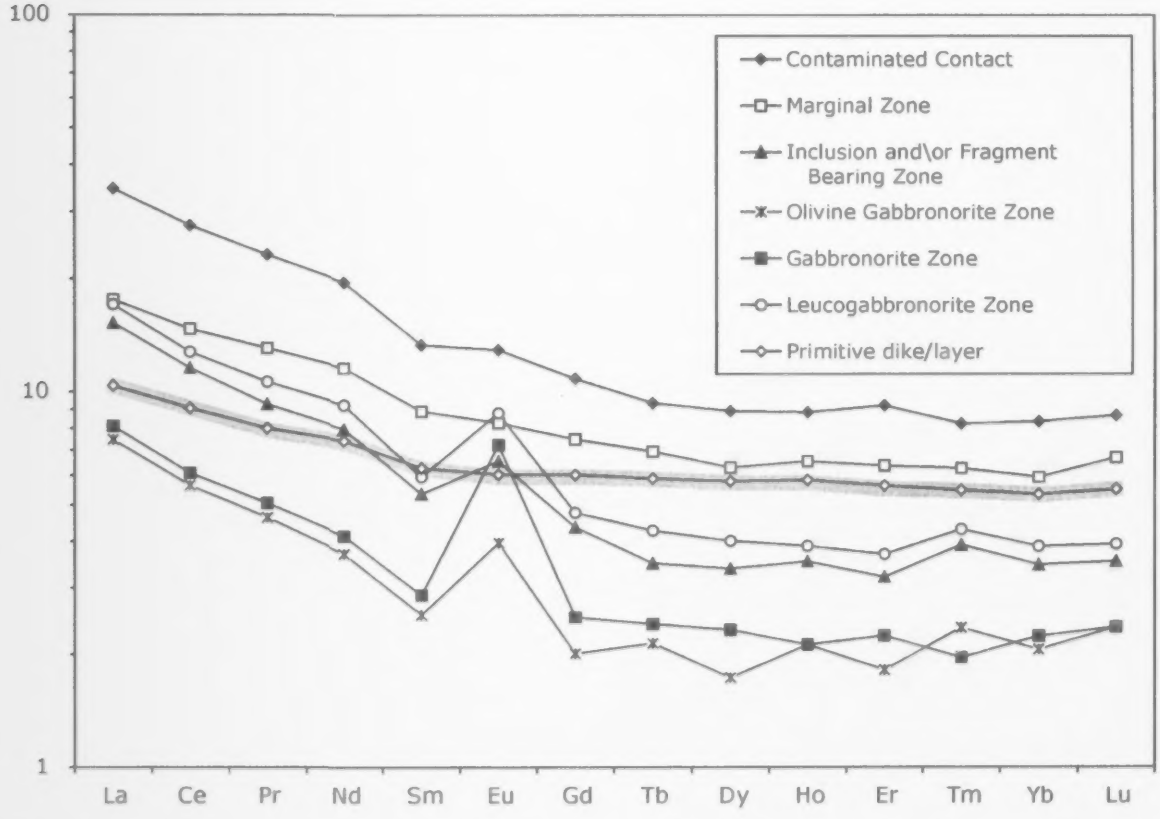

Figure 11. Chondrite-normalized rare earth element plots for the River Valley intrusion for rocks north of the Sturgeon River. Sample from the "primitive dike or layer" may represent the parent magma composition to the mineralized parts of the intrusion in Dana Township.

Table 5. Representative chemical analyses from the River Valley intrusion (data *from* Easton and Hrominchuk 2002).

Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Sample No.	CZ7-500	CZ7-1000	99RME-2242	99RME-2243	99RME-2371A	JLHS1-S3	JLHS2-S1	JLHS2-S4
Zone	MZ	MZ	IFBZ	IFBZ	OLGN	OLGN	GN	GN
Rock Type	fg gabbro-diabase	fg gabbro-diabase	Stop 7, cg troctolite inclusion	Stop 7, mg olivine gabbronorite	cg troctolite	cg mela-troctolite	cg gabbronorite	cg norite
Easting	558431	558431	559150	559149	559597	559657	558643	558644
Northing	5168104	5168604	5167678	5167677	5166341	5166341	5165245	5165393
wt. %								
SiO_2	52.51	51.85	44.14	48.42	43.32	38.30	50.21	50.81
TiO_2	0.93	0.91	0.16	0.21	0.10	0.14	0.13	0.18
Al_2O_3	14.17	14.36	12.79	18.81	18.30	7.85	19.95	18.43
Fe_2O_3	13.40	13.09	2.57	1.51	9.34	15.10	8.23	8.92
FeO	N/A	N/A	13.21	8.38	N/A	N/A	N/A	N/A
MnO	0.17	0.18	0.20	0.14	0.12	0.20	0.13	0.14
MgO	5.16	5.48	15.67	10.16	14.06	23.72	6.90	7.46
CaO	8.79	8.96	7.18	9.82	8.37	3.70	10.32	11.19
Na_2O	2.16	2.25	1.18	1.87	1.34	0.70	2.09	1.87
K_2O	0.85	0.94	0.20	0.30	0.28	0.12	0.21	0.20
P_2O_5	0.09	0.10	0.01	0.03	0.03	0.04	0.03	0.03
CO_2	0.26	0.22	<0.03	00.07	0..22	0..22	0..18	0.15
S	0.024	<0.005	0.67	0.18	<0.005	<0.005	<0.005	<0.005
LOI	1.36	1.60	0.01	0.25	4.51	10.12	1.99	0.43
Total	99.59	99.72	97.32	99.90	99.77	99.99	100.19	99.66
Mg #	40.9	43.0	62.1	62.9	73.0	73.9	60.2	60.1
Ppm								
Cr	90	115	203	250	136	159	73	90
Ni	57	75	1840	623	595	1360	97	92
Co	50	39	119	65	78	155	41	38
Sc	29	30	15	14	11	17	20	28
V	284	287	93	91	43	48	71	109
Cu	171	401	4512	1320	16	162	18	94
Zn	109	108	122	84	92	111	56	66
Rb	37	46	3	5	4	1	16	10
Ba	341	251	81	110	93	79	139	121
Sr	255	193	151	219	235	94	238	220
Nb	2.9	0.9	0.4	0.7	0.3	0.9	0.2	0.2
Zr	86	80	12	21	7	17	3	4
Y	16	18	4	6	4	8	0.7	2
Zr/Y	5.5	4.3	3.0	3.5	1.7	2.2	4.7	2.4
Ppb								
Au	<5	6	145	59	<5	<5	<5	<5
Pt	18	18	576	106	<8	10	<8	11
Pd	19	25	1980	293	<8	11	19	29
Pt/Pd	0.95	0.72	0.30	0.36		0.95		0.38
Total (Au+Pt+Pd)	36	49	2701	458	<21	21	19	40

Abbreviations: cg = coarse-grained, fg = fine-grained, mg = medium-grained, N/A = not analyzed, IBZ = inclusion-bearing zone, GN = gabbronorite zone, LGN = leucogabbronorite zone, MZ = marginal zone, OLGN = olivine gabbronorite zone. Easting and Northings are in UTM Zone 17, datum NAD 83.

Table 5. continued.

Analysis	9	10	11	12	13	14	15
Sample No.	99RME-2116	99RME-2244	99RME-2139	99RME-0375	99RME-0025	99RME-0031	99RME-0137
Zone	LGN	LGN	Footwall	Footwall	Footwall	Dike	Dike
Rock Type	cg gabbro-noritic anorthosite	cg gabbro-noritic anorthosite	Stop 6, alkali-feldspar granite	biotite diorite gneiss	Migmatitic metwacke, Pardo gneiss	Matachewan diabase dike	Sudbury diabase dike
Easting	556346	558522	559785	558780	560005	559913	561255
Northing	5166811	5165429	5167228	5159433	5173855	5174428	5169258
wt. %							
SiO_2	49.59	51.07	72.26	55.29	63.76	50.36	45.50
TiO_2	0.16	0.10	0.10	1.57	0.58	1.15	2.97
Al_2O_3	25.52	22.84	15.21	13.8	15.62	14.07	15.60
Fe_2O_3	1.99	1.08	0.16	3.37	2.09	3.09	2.16
FeO	2.55	4.47	0.44	10.02	3.11	11.11	13.60
MnO	0.07	0.11	0.01	0.17	0.06	0.22	0.23
MgO	3.17	5.38	0.28	3.35	3.08	5.89	5.21
CaO	13.65	10.91	1.14	6.73	3.23	10.02	8.21
Na_2O	2.41	3.03	4.02	2.58	3.63	1.97	3.26
K_2O	0.30	0.22	5.52	1.94	2.97	0.68	1.45
P_2O_5	0.01	0.01	0.03	0.19	0.13	0.12	0.75
CO_2	0.03	0.08	0.20	0.11	0.12	<0.03	0.12
S	<0.01	<0.01	<0.01	0.04	0.09	0.12	0.12
LOI	0.98	0.72	0.61	0.76	1.18	0.68	0.09
Total	100.40	99.94	99.78	99.77	99.44	99.36	99.03
Mg #	54.2	61.6	46.1	31.4	52.4	43.0	37.4
Ppm							
Cr	138	86	20	30	183	90	37
Ni	44	83	<5	57	64	81	68
Co	13	28	<5	41	19	57	57
Sc	13	11	<1	26	9	37	26
V	75	55	11	330	17	319	204
Cu	46	18	<5	92	10	278	71
Zn	36	51	15	142	94	67	190
Rb	4	3	106	75	139	13	41
Ba	85	89	1748	593	670	91	673
Sr	258	246	950	157	464	145	250
Nb	0.4	0.1	1.2	12.5	6.8	4.8	21.6
Zr	9	3	93	166	117	92	348
Y	5	2	1	47	8	31	59
Zr/Y	1.8	1.5	93	3.5	14.6	3.0	5.9
Ppb							
Au	5	<5	<5	9	<5	7	<5
Pt	15	<8	<8	6	<8	38	<8
Pd	19	<8	<8	14	<8	72	<8
Pt/Pd	0.79			0.43		0.53	
Total (Au+Pt+Pd)	39	<21	<21	29	<21	117	<21

Abbreviations: cg = coarse-grained, fg = fine-grained; mg = medium-grained; N/A = not analyzed; IBZ = inclusion-bearing zone, GN = gabbronorite zone, LGN = leucogabbronorite zone, MZ = marginal zone, OLGN = olivine gabbronorite zone. Easting and Northings are in UTM Zone 17, datum NAD 83.

ROAD LOG, DAY 3, RIVER VALLEY INTRUSION

Note: Highway 805 is used regularly by logging trucks. Consequently, extreme caution should be taken when parking vehicles on the shoulder of the highway and when examining outcrops located along Highway 805.

Geological map reference: Lumbers (1973); Card and Lumbers (1975); Easton and Hrominchuk (2001a, 2001b), Easton (2001).

0.0 km	Start at the junction of Highway 69S and the Highway 17 southeast bypass. Get on the bypass heading east toward Coniston and North Bay.
11.8 km	Junction Highway 17 and southeast bypass, turn right onto Highway 17 and head east toward North Bay.
20.0 km	Bridge over the Wanapitei River. The river lies along the trace of the Grenville Front.
30.0 km	Pull off onto a pullout located on the south side of Highway 17.

Stop 1. Shear-Zone Hosted Orthopyroxene Hornblendite Body

Examine the outcrop and large blasted boulders present on the west side of the pullout. They belong to an orthopyroxene hornblendite body that is present within a high-strain zone that extends subparallel to the highway. Examples of these highly strained felsic gneisses can be examined in outcrops at the base of the hill east of the pullout. The top of the ridge south of the road and above the stop consists of layered leucogabbronorite of the East Bull Lake intrusive suite. Thus, although proximal to rocks of the suite here, the orthopyroxenite body is not directly in contact with the suite, although that relationship has been observed elsewhere in Street and Awrey townships (Easton and Murphy 2002). Note the large, equant, orthopyroxene crystals, and the fine-grained amphibole matrix. Return to vehicles and head east on Highway 17.

60.6 km	Junction of Highway 17 and 539 in Warren. Turn north onto Highway 539, reset odometer to zero.
0.0 km	Junction, Highway 17 and 539 in Warren, turn north onto Highway 539 and proceed toward River Valley. After heading 200 m north on Highway 539, turn right, then after going 100 m east, turn left and continue north on Highway 539.
4.8 km	Coloured Aggregates Limited/Crea-Mac quarry operation is located east of the highway. This operation is one of several quarries in Ratter Township which produces pink aggregate from syenite pegmatite of probable Archean age that occur within this part of the Grenville Province.
8.3 km	Junction Highway 539 and Kipling Road West, continue north on Highway 539.
12.5 km	Outcrops on both sides of the road expose typical rocks of the Crerar gneiss association, which consists of granodiorite, tonalite, and amphibolite rocks (2680 to 2660 Ma), commonly migmatized. Tight to isoclinal folds are common in the outcrop on the east side of the road.
14.5 km	Pull over onto right shoulder and park by outcrops at crest of hill.

Stop 2. Rocks of the Crerar Gneiss Association

This outcrop illustrates typical mafic and intermediate composition gneisses of the Crerar gneiss association (Easton 2003), including tonalite, 2 phases of granodiorite, amphibolite layers and pods, and minor calc-silicate rock. Rocks of the Crerar gneiss association form the country rocks to the southern margin of the River Valley intrusion. A sample from this outcrop yielded a Nd/Sm model age of 2710 Ma (Dickin 1998). Return to vehicles and continue northward on Highway 539.

21.6 Park on shoulder of road by large, isolated outcrop knob on east side of the highway.

Optional Stop. Crerar Gneiss Association

UTM 561947E, 5157087N. The outcrop on the east side of the road exposes a megacrystic granodiorite, which is a late intrusion into the Crerar gneiss association. This rock cuts earlier migmatitic fabrics, but is itself locally strongly deformed. A sample from this outcrop has yielded a U/Pb zircon age of 2663±4 Ma, with titanite dating the waning of Grenville metamorphism at 974±12 Ma (Easton and Kamo 2003). Return to vehicles and continue northward on Highway 539.

23.1 km Bridge over the Sturgeon River.

23.6 km Junction Highway 539, which heads east toward Field, and Highway 539A, which heads west-northwest toward River Valley. Turn left. Immediately pull over and park for optional stop.

Optional Stop. Red Cedar Lake Gneiss

This is Stop 2.3 of Lumbers (1978). Outcrops north of the highway at and just west of the junction expose typical granular gneiss of the Red Cedar Lake gneiss. The Red Cedar Lake gneiss is a widespread unit that extends from its western terminus here, at the Sturgeon River, east to the Ottawa River, a distance of over 80 km. It is thought to be a diatextite derived from Archean metasedimentary and intermediate composition intrusive rocks (Easton 2003), and forms the country rock along the eastern side of the River Valley intrusion north of the Sturgeon River. Much of the texture in the gneiss is probably Archean, rather than Grenvillian, in age. Return to vehicles and continue northward on Highway 539.

24.9 km Dupras Store in "downtown" River Valley.

26.2 km Bridge across the Temagami River.

27.6 km Junction Highway 539A and Erana Mines Road. The Erana Mines Road leads to Erana building stone quarry and Crea-Mac aggregate quarry, both are hosted in well-preserved rocks of the Gabbronorite Zone of the River Valley intrusion.

29.5 km End Highway 539A, start Highway 805. End of continuously paved road.

29.55 to 29.9 Pull over and park by the shoulder at roughly 29.55 km. The 350 m long section of outcrop on the north side of the road constitutes Stop 3.

Stop 3. Varied Degrees of Preservation in Rocks of the River Valley Intrusion

This is Stop 2.4 of Lumbers (1978). UTM at the west end of the outcrop is 559691E, 5163308N. This 350 m long section along the north side of the highway exposes rocks of the River Valley intrusion exhibiting a wide variety of textures and deformation. The east end of the outcrop consists of dark-grey to grey weathering gabbronorite and leucogabbronorite, with well-preserved plagioclase laths and only incipient corona development around mafic minerals. As one proceeds east, the rocks become paler, largely due to whitening of the plagioclase grains during recrystallization. Note the presence of many small, thin, anastomosing shear zones. Heading west, the outcrop becomes a black and white leucogabbronorite, then a foliated equivalent of the same, finally becoming protomylonitic to gneissic at the west end of the outcrop where the road curves slightly. The variation seen in this outcrop is typical of the variation in the degree of preservation and deformation observed throughout the River Valley intrusion north of the Sturgeon River. In general, well-preserved, little-deformed igneous rocks form the core of topographic highs, whereas valleys and low areas are generally underlain by gneissic rocks similar to those observed in the west end of this outcrop. South of the Sturgeon River, recrystallized to gneissic varieties of gabbronorite and leucogabbronorite predominate.

30.2 km — Junction with Giroux road. Turn right (north) and proceed north on gravel road. Note that the road is gated. Seek permission (and key) for entry from Mr. Giroux, who lives in the house just east of the gate.

31.3 km — Road crosses Azen Creek, a major north-northeast-trending deformation zone within the River Valley intrusion. Most of the copper-nickel-PGE mineralization in the River Valley intrusion lies to the west of the Azen Creek zone, even though similar rock units occur along the contact of the intrusion to the east of the Azen Creek shear zone.

31.8 km — Junction, stay to the left and follow side road roughly 600 m to the first of several quarry pits present in the Dana quarry. Park at base of hill by first large cliff face, just past the large quarry building. Proceed uphill along the sideroad to the west (right) to large open area of outcrop.

Stop 4. Autolith Fragments and Layering, Layered Gabbronorite Zone

This is the southernmost quarry face of a large building stone quarry, which has been exploited at various times over the last 30 years. Stone from this quarry face was used as floor tiles in the Willet Green Miller Centre, Ministry of Northern Developments and Mines, at Laurentian University in Sudbury. The rocks exposed here span nearly the entire Layered Gabbronorite zone, ranging from olivine-bearing norite in the south part of the exposure to a pigeonite gabbro in the northwest part. The dominant rock type here is a very coarse-grained, black norite to gabbronorite with varied amounts of oxide minerals in addition to metamorphic amphibole and garnet. Layering is almost horizontal in this area (~15 to 25°). Layering is subtle, and commonly disrupted or convoluted. Pods, dikes and irregular layers of pegmatitic and granophyric material are found in the more central region of this outcrop area. Pegmatite and granophyre commonly occur together and in association with mafic cognate inclusions and felsic fragments. The development of very coarse grains of pyroxene, plagioclase, amphibole and magnetite around these inclusions led Hrominchuk (2000) to conclude that these pods and dikes were not formed simply by differentiating magma. He suggested that they may have formed by contamination of a relatively unfractionated magma (olivine norite) by cooler, compositionally different, footwall and cognate xenoliths. These pegmatitic patches are very similar to those developed in the Inclusion-Bearing zone, which we will see subsequently at Stop 7.

If one continues to follow the road north, it passes by an abandoned quarry pit at 400 m and ends above another 20 m high quarry face at 600 m. In this quarry, subtle, shallow dipping (~15 to 25°) layering is present (*see* Photo 11d) as are pegmatitic veins and pods. Unlike the main stop, mafic cognate inclusions and disrupted layering are not observed. Turn vehicles around and retrace road back to main gravel road.

32.5 km Junction, continue north on main road.

34.4 km Pull off onto small road to the left (west) of the road and park. Follow old skidder trail through the bush west for approximately 200 m to the top of a cliff face, then work your way down safely along the side of the cliff. **Watch for loose rocks on the slope and falling rocks.**

Stop 5. Layered Olivine Gabbronorite

This stop displays olivine-rich rocks of the Olivine Gabbronorite zone, which may be stratigraphically equivalent to the Olivine Gabbronorite zones in both the East Bull Lake and Agnew Lake intrusions (*see* Table 5, analyses 5 and 6). The sequence of olivine-bearing rocks here is roughly 30 m thick. The section grades upward from melatroctolite to orthopyroxene oikocrystic melatroctolite near the base to a clinopyroxene-bearing orthopyroxene melatroctolite near the top. Layering is well developed in the lower portion of the cliff face and contains erosive scours that grade from plagioclase-poor olivine cumulates to more plagioclase-rich troctolites. All olivine in the section is partially to extensively serpentinized, creating a fractured and rubbly appearance. Plagioclase in this zone is generally interstitial with some euhedral primocrysts. Mineral compositions obtained by Hrominchuk (2000) are plagioclase, An_{70-76}; olivine, Fo_{72}; orthopyroxene forms oikocrystic or euhedral primocrysts at En_{70} and clinopyroxene is either absent or interstitial. Low-temperature alteration of the olivine-rich rocks produces serpentine, carbonate and magnetite. Return to vehicles, continue north on gravel road.

35.5 km Junction with side road to Azen Creek occurrence to the left (west), continue on main road.

36.3 km Park vehicles and walk south to clean outcrop exposures.

Stop 6. Footwall Alkali Feldspar Granite and Sudbury Diabase Dike

This quick stop shows a few outcrops of a weakly foliated alkali granite, which is the main footwall rock type to the River Valley intrusion north of the Sturgeon River in Dana Township. This granite cuts the migmatitic, metasedimentary-derived Pardo gneiss. Lumbers (1973) classified these granitoid rocks as monzonite to quartz syenite; however, geochemistry (Easton 2003; *see* also Table 5, analysis 11) suggests that these rocks are more appropriately termed alkali feldspar granite using the normative classification of Streckeisen (1976). The alkali feldspar granites are peraluminous, with low total REE (less than 50 ppm), positive Eu anomalies (Eu/Eu* 7.9), and are corundum-normative, suggesting an S-type (sedimentary-derived) affinity. Breaks and Moore (1992) reported similar REE patterns from their Type 2 phase of the Neoarchean, peraluminous, S-type Ghost Lake batholith in northwest Ontario, and suggested that the unusual chemistry of these rocks resulted from feldspar accumulation. U/Pb zircon geochronology from this outcrop yielded an age of 2660 Ma (Easton and Kamo 2003). Although we are at least 300 m north of the contact with the River Valley intrusion at this point, lead loss related to emplacement of the intrusion at 2475 Ma has affected this granite, and prevents determination of a more precise age. Titanite from this outcrop gives an age of 966±6Ma (Easton and Kamo 2003), confirming that these rocks, as well as the River Valley intrusion, have been affected by Grenvillian metamorphism. As was the case for the Parisien Lake syenite adjacent to the East Bull Lake Intrusion, this granite was originally thought to be a felsic differentiate that was coeval with the River Valley intrusion (e.g., Card and Lumbers 1975).

Also present in the outcrop is a Sudbury swarm diabase dike. In the Southern Province, the Sudbury swarm dikes trend northwesterly, and consist of titaniferous (2.5 to 3.5 wt. % TiO_2; see also Table 5, analysis 15) olivine-biotite-magnetite-gabbros. In Dana Township, Sudbury swarm dikes generally show northwest or northerly trends, and can be traced for several hundreds of metres along strike. Dikes range in size from a few centimetres in width to greater than 100 m wide. Olivine in the Sudbury swarm dikes north of the Sturgeon River commonly show incipient corona formation, similar to that observed in the River Valley intrusion, suggesting that coronas in both rock types developed in response to Grenvillian metamorphism. Sudbury swarm dikes south of the Sturgeon River are more extensively metamorphosed, exhibiting nearly complete replacement of olivine by orthopyroxene, spinel and garnet, and dike segments are shorter and more randomly orientated. UTM 559785E, 5167228N. Return to vehicles, turn around and retrace route.

37.1 km Sideroad to Azen Creek occurrence, turn right (west) and proceed roughly 500 metres to stripped outcrops.

Stop 7. Azen Creek Copper-Nickel-PGE Occurrence

The Azen Creek zone was one of the initial discovery sites for PGE mineralization in the River Valley intrusion in the fall of 1998. Its location along the north contact of the intrusion, some 6 km from Dana Lake, was the first indication that PGE mineralization might occur discontinuously to continuously over a considerable strike length. The stripped area south of the road contains inclusions of medium-grained gabbronorite, troctolite, amphibolite, alkali feldspar granite and other felsic material within a medium-grained, grey-green olivine gabbronorite. Inclusions are more abundant on the west side of the stripped area, and vary from centimetre- to metre-scale. Mineralization consists of finely disseminated chalcopyrite and pyrrhotite in the matrix, as well as some sulphide-rich inclusions. Hrominchuk and Jobin-Bevans (2000) suggested that the inclusion-bearing zone might be intrusive into the contact zone of the intrusion, roughly coincident with the boundary between the fine-grained contact zone rocks and overlying olivine-rich cumulates of the Olivine Gabbronorite zone (e.g., Stop 5).

The stripped area north of the road contains less mineralization, but shows a variety of pegmatitic veins and pods. The pegmatitic pods are commonly cored by inclusions of felsic material, likely incorporated from the footwall of the intrusion. Return to vehicles, turn around, and retrace route to Highway 805.

0.0 km Junction with Highway 805, reset odometer to zero. Proceed west on Highway 805.

0.3 km Highway bends south, side road heads west to Upper Canada Stone Company and Giroux gravel pit. Note piles of crushed, black aggregate derived from the well-preserved gabbronorite of the River Valley intrusion. From this point westward, the road parallels the Sturgeon River on the south, as well as winding its way back and forth across an abandoned Canadian National Railways right-of-way.

1.4 to 1.1 km High ridges to the north of the road are well preserved gabbronorite of the River Valley intrusion.

5.4 km Outcrop ridge north of the road and the right-of-way consists of gabbronorite of the River Valley intrusion which contains 2 fabrics, the later fabric being parallel to the Sturgeon River. Rocks similar to these were previously mapped as being deformed equivalents of Nipissing gabbro (Dressler 1979), however, chemically and petrographically they belong to the River Valley intrusion.

6.8 km Road turns north at Glen Afton. Glen Afton lies near the eastern margin of the 1 to 2 km wide boundary zone that marks the Grenville–Southern Province boundary in this area. For the next 20 km, Highway 805 weaves back and forth across this boundary zone, exposing zones of intense mylonization separated by lenses of relatively well-preserved rocks of the Huronian Supergroup, the River Valley intrusion, and the Nipissing intrusive suite. Note that Highway 805 was re-aligned between 1988 and 1989; consequently, users of Davidson's (1986) guidebook for the Grenville Front in this area are cautioned that the distances and stop locations listed in that guide are not always easily determined. Where possible, this guide notes the location of some of Davidson's stops.

7.0 km Park vehicles just past old railroad right-of-way and examine outcrops on west side of Highway.

Optional Stop. Huronian Metavolcanic Rocks

This is Stop 2.6 of Lumbers (1978). UTM for the south outcrop 554000E, 5166220N; for the north outcrop 554005E 5166267N. The outcrop just north and west of the abandoned right-of-way consists of medium-layered dacite, which may be part of the Stobie Formation of the Huronian Supergroup. The low outcrop beside the road (100 m to the north) consists of felsic to intermediate pyroclastic rocks assigned to the Huronian Supergroup. These outcrops represent the easternmost exter.: of Huronian felsic metavolcanic rocks that have been recognized to date. It is difficult to differentiate fine-grained metavolcanic rocks from mylonitic rocks along the Grenville Front, due to the intensity of the deformation. Return to vehicles and continue north on Highway 805.

8.0-8.2 km Outcrops west of the highway consist of fine-grained amphibolite, possibly representing Huronian Supergroup metavolcanic rocks, whereas outcrops east of the highway, generally covered by vegetation, consist of deformed leucogabbronorite of the River Valley intrusion.

9.5 km Low outcrops of gneissic leucogabbronorite of the River Valley intrusion occur on both sides of the road.

9.8 km ATV trail to Lismer's Ridge area on property of Pacific North West Capital Corporation on the right (east).

10.1 to 10.6 km Outcrops in this stretch of road, particularly those on the north side of the road, represent an optional stop.

Optional Stop. Variably Preserved Nipissing Gabbro

This location approximates Stop 2.7 of Lumbers (1978). The highway transects a body of Nipissing gabbro that has intruded the River Valley intrusion. Outcrop exposures on the north side of the road, in the vicinity of UTM 554777E 5168511N, exhibit varied degrees of preservation of the Nipissing rocks, similar to that observed in rocks of the River Valley intrusion. Dark green to almost black-weathering rocks are Nipissing gabbro retaining primary orthopyroxene and minor olivine grains, whereas green-weathering outcrops consist of typical, greenschist-grade, amphibolitized Nipissing gabbro, typical of what most of these rocks look like in the Southern Province. Note that plagioclase is much less abundant in the Nipissing rocks than in the River Valley intrusion. Return to vehicles and continue north on Highway 805.

10.7 km Outcrops north of road consist of protomylonitic gabbronorite of the River Valley intrusion and ultramylonite of unknown protolith.

10.9 to 11.1 km Outcrops east of the road consist of foliated to protomylonitic leucogabbronorite of the River Valley intrusion, intruded by deformed, pink felsite veins that are chemically similar to Huronian Supergroup felsic metavolcanic rocks (Easton 2003). UTM 554415E, 5168855N.

11.2 km Outcrop east of the road consists of varitextured gabbro of the River Valley intrusion. UTM 554500E, 5169105N.

11.8 km Park vehicles and examine outcrops on east side of road.

Stop 8. Mylonitized Anorthosite of the River Valley Intrusion

This is Stop R6a of Davidson (1986) and Stop 2.8 of Lumbers (1978). Outcrops west of the road consist of ultramylonite derived from rocks of the River Valley intrusion. Please note a few large blocks in the area, in which mylonitic texture is developed in rocks that compositionally are anorthosite. Return to vehicles and continue north on Highway 805.

12.0-12.2 km Road extends uphill and around a curve, passing through outcrops of greenish weathering Nipissing gabbro. This curve is the location of stop R5 of Davidson (1986).

12.3 km Outcrops on both sides of the road consist of black, flinty, ultramylonite of unknown protolith, but which may be derived, in part, from Huronian felsic metavolcanic rocks. This outcrop approximates stop R4 of Davidson (1986).

12.5 km Outcrop west of road consists of boulder conglomerate, likely belonging to the Gowganda Formation, in contact with weathered granite of unknown age. Outcrops east of the road are a black, flinty ultramylonite (UTM 554057E, 5170254N). The section of road between kilometre 11.8 and 12.5 illustrates the rapid transition between weakly deformed and intensely deformed rocks within the Southern–Grenville province boundary. Metasedimentary and metavolcanic rocks of the Huronian Supergroup occur in close proximity to rocks of the River Valley intrusion in this area, but deformation has obscured primary contacts.

13.3 km Outcrops on curve consist of felsite and black, flinty ultramylonite.

15.1 km Pull over and park, examine outcrops on the east side of Highway 805.

Optional Stop. Mississagi Formation and Mylonitic Contact with the River Valley Intrusion

This is Stop R3a and R3c of Davidson (1986). Outcrops on the east side of Highway 805 consist of deformed quartz arenite of the Mississagi Formation. UTM of road outcrop is 554413E, 5172600N. Proceed east through the bush for approximately 100 m to a cliff face. Black, flinty ultramylonite occurs at the base of the cliff, above quartz arenite of the Mississagi Formation. The mylonite is graditional upward, over about 1 to 3 m, into foliated leucogabbronorite of the River Valley intrusion. The Dana North zone, at the next field trip stop, occurs about 50 m stratigraphically above this location, and about 400 m east of this stop. Return to vehicles and continue north on Highway 805.

15.5 km Turnoff on right (east) leads to Pacific North West Capital Corporation Dana North exploration area.

16.3 km Junction, continue south roughly 500 m on road and park in flat area opposite large stripped outcrop.

Stop 9. Dana Lake Copper-Nickel-PGE Occurrence

Prospectors L. Luhta, R. Bailey and R. Orchard first reported promising platinum-group element assay values from rocks of the River Valley intrusion near Dana Lake and Azen Creek in November 1998. Subsequently, Pacific North West Capital Corporation optioned and staked most of the north contact of the River Valley intrusion in Dana Township (inset map in Figure 12). Mustang Minerals Corporation optioned and staked most of the River Valley intrusion in Crerar Township, as well as part of the north contact near the Dana–McWilliams Township boundary. As of this writing, Pacific North West Capital Corporation has identified a dozen exploration targets along this northern contact. These are, from northwest to southeast, the Pardo, Dana North, Dana South, Banshee, Lismer's Ridge (Lismer's North and Lismer's South), Macdonald, Varley, Azen, Jackson's Flats, and Razor zones. The Thomson zone is located more centrally in the intrusion.

Between 2000 and spring 2003, Pacific North West Capital Corporation, in conjunction with their partner, Anglo American Platinum Corporation Limited, had completed 5 diamond-drill programs. Approximately 288 diamond-drill holes totalling 58 000 m have been completed on their River Valley intrusion property in Dana Township. Diamond drilling was focussed almost entirely on the Dana North (*see* Figure 12) and Lismer's Ridge targets. A 6th diamond-drill program, aiming for a potential total of another 40 000 m of diamond-drill core, is underway, also focussing mainly on the Dana North and Lismer's Ridge zones (Pacific North West Capital Corporation, Press Release, April 10, 2003; http://www.pfncapital.com/s/NewsReleases). The scope of these diamond drilling programs is too large to effectively summarize herein; consequently, the reader is referred to the comprehensive assessment file reports (Resident Geologist's office, Sudbury) related to these programs.

Pacific North West Capital Corporation has released 2 Mineral Resource estimates for the Dana North zone, based on the Phase 1 to 5 drilling programs. In both cases, Derry, Michener, Booth and Wahl Consultants Limited conducted the resource studies. The first *in situ* resource estimate (Pacific North West Capital Corporation, Press Release, October 16, 2001) was a total measured, identified and inferred resource of 593 000 ounces palladium, platinum and gold at Dana North, Dana South and Lismer's Ridge. This estimate used a 0.7 g/t Pt+Pd cut-off grade, and can also be expressed as 12.7 million tonnes at 1.46 g/t Pt+Pd+Au. This can be broken down into 7.74 million tonnes at 1.60 g/t Pt+Pd+Au at Dana North and South, and 4.97 million tonnes at 1.24 g/t Pt+Pd+Au at Lismer's Ridge.

The second Mineral Resource estimate (Pacific North West Capital Corporation, Press Release, October 17, 2002) was a total measured and indicated resource of 825 900 ounces palladium, platinum and gold. There were inferred resources of 200 600 ounces palladium, platinum and gold, yielding a total of 1 026 500 ounces at Dana North and Lismer's Ridge. This estimate used a 0.7 g/t Pt+Pd cut-off grade, and can also be expressed as 18.1 million tonnes of measured and indicated at 1.36 g/t Pt+Pd and 5.4 million tonnes inferred at 1.11 g/t Pt+Pd. Roughly 60% of this resource is in the Dana North area.

A description of the Dana North zone has been published by S. Jobin-Bevans, Projects Manager for Pacific North West Capital Corporation, in James et al. (2002b). The description below, in a slightly smaller font, is derived from that published report.

The distribution of the marginal Inclusion-bearing/Breccia zone (roughly equivalent to the Inclusion- and/or Fragment-bearing zone of Hrominchuk (2000) and James et al. (2002a)), the loci of mineralization, is in abrupt, intrusive contact to the east with the Neoarchean-age Pardo gneiss, and to the west these zones are replaced by a weakly layered to massive leucogabbro-gabbro-melagabbro sequence. Small pod-like, alkalic intrusions of unknown age are observed at two places along the intrusive contact where they displace the Inclusion-bearing/Breccia Zone. As well, faults related to the Grenville Front and a 1238 Ma Sudbury swarm olivine-magnetite gabbro dyke cut or displace this zone. Silicate assemblages that host the mineralization in this part of the

River Valley intrusion exhibit upper greenschist facies mineralogy in contrast to the upper amphibolite facies and preserved magmatic assemblages that dominate the remainder of the intrusion. The stratigraphy of the Inclusion-bearing/Breccia Zone is normally ~100 m wide in plan view. From the footwall Pardo gneiss, westward into the intrusion, the sequence and character of the distinguishable units are:

1. *Footwall Breccia Unit:* typically 5 to 15 m wide, but may be absent. It consists of partly rounded to angular, centimetre- to decimetre-size fragments of country rock (~75%; Pardo gneiss, Archean gabbro, diabase, diorite, minor Huronian Supergroup metasedimentary rocks) and River Valley intrusion material (~25%; chilled gabbro and medium-grained melagabbro) in a matrix of finer grained rock of similar composition and (or) an aplitic to granitic matrix. A narrow zone of migmatite at the contact of the intrusion is probably due to contact metamorphism, and granitic veins can be traced from this unit into the footwall at Lismer's Ridge. Sulphide minerals are dominantly pyrite and pyrrhotite with local areas of trace to 1 volume percent chalcopyrite + pyrrhotite. Platinum group element concentrations are normally less than 25 ppb.

2. *Boundary Unit:* 5 to 20 m wide, but may be absent. It contains partly rounded to subangular, centimetre- and decimetre-size fragments of country rock (typically 10-25%), and cognate xenoliths of melagabbro, gabbro and less commonly leucogabbro to anorthosite in a matrix of gabbro to melagabbro ± aplite/granite, as in the Footwall Breccia. Sulphide minerals are mainly pyrite and pyrrhotite, locally up to 3 volume percent chalcopyrite + pyrrhotite occur; platinum group element contents are typically <75 ppb with local concentrations greater than 1000 ppb.

3. *Breccia Unit:* 20 m wide to greater than 100 m. It contains as much as 95% dominantly cognate xenoliths of gabbro to melagabbro and subordinate leucogabbro in a medium-grained matrix of similar composition; fragments are partly rounded to round probably due to partial assimilation, and centimetre to decimetre in size. Those greater than a metre are mainly footwall compositions (including Huronian Supergroup metasedimentary rocks) and tend to be larger with increasing proximity to the intrusive contact. Sulphide minerals (1 to 5 volume percent pyrrhotite + chalcopyrite) occur as both bleb and disseminated types; platinum group element contents are highly varied, but most values range from 500-6000 ppb with local concentrations greater than 10,000 ppb.

4. *Inclusion-bearing Unit*: 10 to 50 m wide. It contains >90% autoliths of leucogabbro, subordinate gabbro and less melagabbro in a matrix of either medium-grained leucogabbro or gabbro; the leucogabbro xenoliths are subangular to partly rounded, dominantly decimetre to metre in scale, and appear to be stoped inclusions from the adjacent (overlying) Leucogabbronorite zone. Sulphide minerals include trace to 3 volume percent pyrrhotite + chalcopyrite; platinum group element contents range from 100-500 ppb with local concentrations greater than 1000 ppb.

Interestingly, the Breccia Unit, which shows the highest and most persistent sulphide-associated platinum group element mineralization, has the smallest proportion of footwall inclusions (<1%); perhaps an indication that chemical contamination from footwall lithologies is not a major controlling factor on mineralization.

Fine-grained gabbro and diabase dikes cut all of the above units as well as the Leucogabbronorite zone in the main part of the intrusion. These dikes are metamorphosed at a grade similar to the intrusion in the Dana North area and are distinct from younger dikes of the Sudbury swarm.

Drill hole data suggest that the dip of the contact of the Inclusion-bearing/Breccia zone with the footwall is at least 45° to 65° and toward the intrusion, whereas the apparent dip of the surface between the Inclusion-bearing Unit and Breccia Unit is steeper (~70°) and toward the intrusive contact. The attitude of metre-scale layering in the Leucogabbronorite zone adjacent to the mineralized Inclusion-bearing/Breccia zone is poorly constrained but is estimated to be near-vertical (~70° to 90° west and east) and possibly shallowing (i.e. less than 70° west dip) westward into the intrusion.

S/Se ratios for 13 of 15 samples (mineralized and barren) from the Dana North and Lismer's Ridge areas have values from 500 to 2120, which are well within the magmatic range indicted by the Merensky and J-M reefs, and Konttijarvi-Portimo contact-type mineralization (i.e., 700-800 S/Se). Footwall rocks have low Pt, Pd and Au, and Pd/Pt and Cu/Ni are less than 1; these metal values indicate that the Archean footwall rocks are not genetically related to the platinum group element mineralizing event(s). Estimates of the metal values for barren magma that forms large parts of the intrusion or which are feeders, have less than 100 ppm Cu and anomalous Pt + Pd

concentrations averaging 32 to 35 ppb, but their metal ratios, Pd/Pt and Cu/Ni, are both less than 1, which is unlike mineralized samples (*see* below). Analytical data for sulphide-bearing felsic and mafic dikes and the Boundary, Breccia and Inclusion-bearing Units all show moderate to high average Pt+Pd (peaking in the Breccia Unit, as expected), and all show Pd/Pt and Cu/Ni ratios based on metal averages in the range 1.1-4.8, distinct from the low sulphide, Cu-poor assemblages. The mineralized zones at the Bull Frog Zone of the East Bull Lake Intrusion show the same geochemical features.

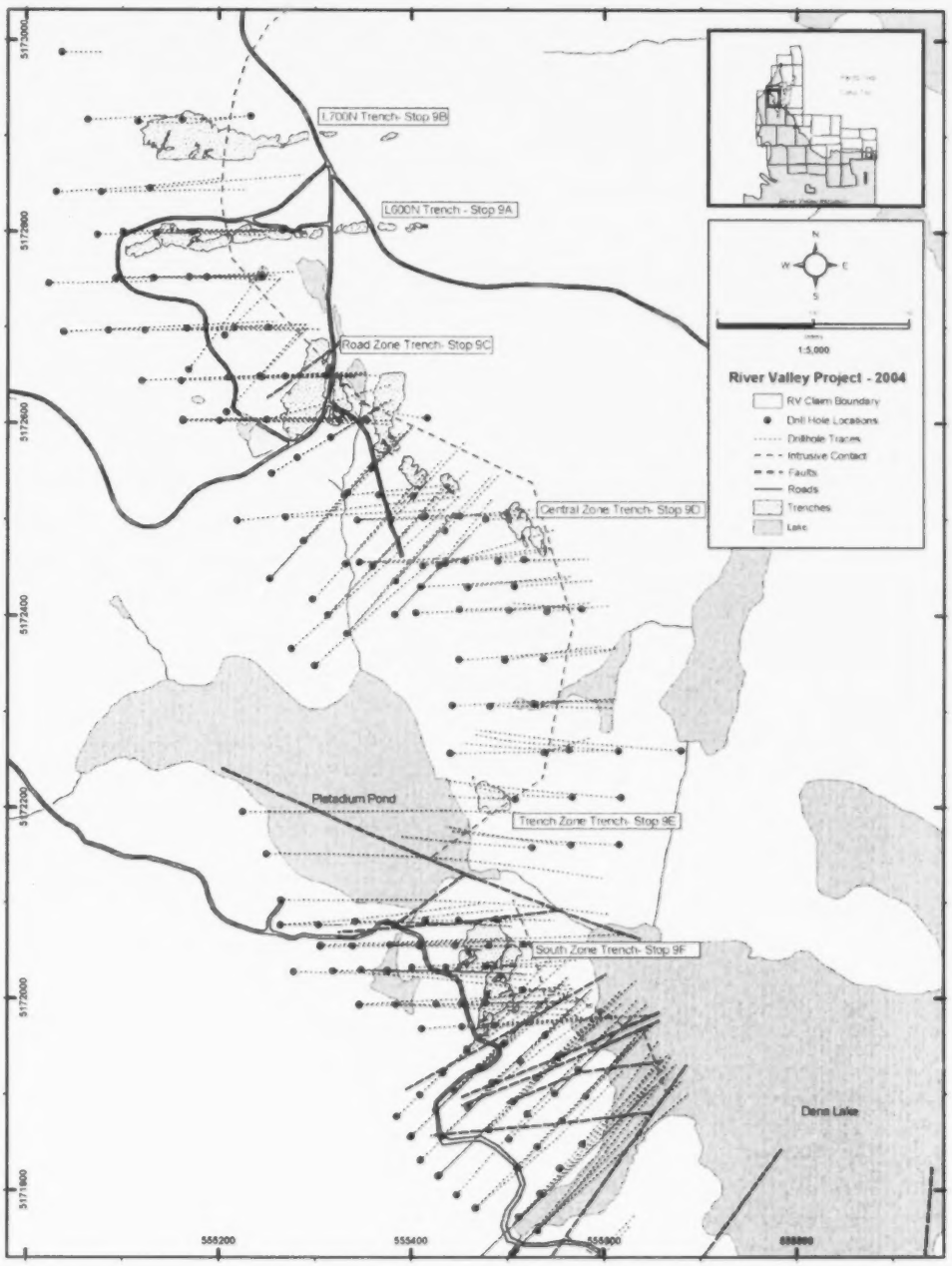

Figure 12. Map of the Dana North property of Pacific North West Capital Corporation, showing the location of stops 9A through 9F, as well as the extent of the drilling program undertaken between 1999 and 2002.

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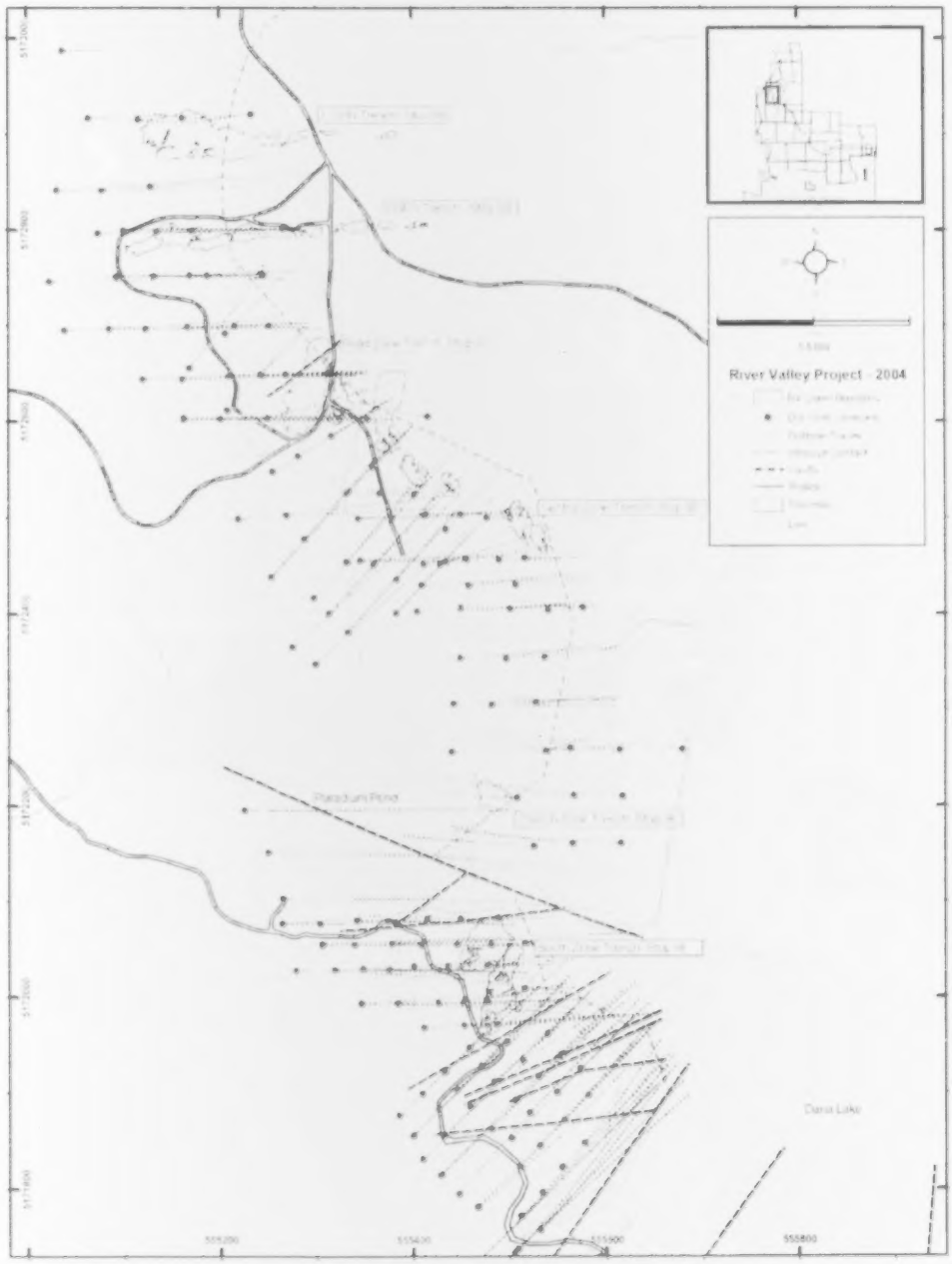

Figure 12. Map of the Dana North property of Pacific North West Capital Corporation, showing the location of stops 9A through 9F, as well as the extent of the drilling program undertaken between 1999 and 2002.

Stop 9 is located on the Pacific North West Capital Corporation property, and consists of an examination of several outcrop areas that were exposed between 1999 and 2001 (*see* Figure 12). These outcrops provide an excellent opportunity to examine the contact of the River Valley intrusion, the mineralized zones and the character of the inclusion-bearing unit (Photo 13). Stop 9, Day 3, makes for an interesting comparison with Stop 11, Day 1, the traverse across the East Bull Lake mineralized contact in the Moon Lake area.

STOP 9A. L6+00N, CONTACT ENVIRONMENT

The line 6+00N clearing to the west of the road was completed in May 2000 in order to expose and sample the up-dip geology and mineralization intersected in diamond-drill hole RV00-08. This clearing provides excellent exposure of the stratigraphy in the contact environment. Walk to the western edge of the cleared area, and then walk back past diamond-drill hole collar RV00-08 toward the road. This will bring you from massive gabbronorite through the inclusion-bearing zone at the west end of the clearing through to the footwall Archean migmatite, paragneiss and gabbroic rocks at the east end of the clearing. The highest assay value from samples collected in this area is 10.1 g/t Au+Pd+Pt (sample L6N-09). Note that the footwall gneisses are pale green and washed out, reflecting a regional chloritic alteration zone, first noted by Lumbers (1973), which affects all rock units in northwest Dana Township and southwest Pardo Township.

Walk north and across the access road for about 100 m to the next clearing to the east that intersects the road, this is grid line 7+00N.

STOP 9B. L7+00N, CONTACT ENVIRONMENT

The line 7+00N clearing was completed in May to June 2000 in order to expose and sample an extensive induced polarization chargeability anomaly outlined in this area. This clearing offers excellent exposure of the stratigraphy in the contact environment including numerous complex structural features that crosscut both country rocks and intrusive rocks. As on line 6+00N, walk to the western edge of the cleared area, then walk back toward the road. Diamond-drill hole collars RV00-23 and 24 are located at the north edge of the clearing, on your left. Pay special attention to the extensive east-northeast trending mylonite zone that cuts across the exposure. The highest assay value from samples collected in this area is 8.6 g/t Au+Pd+Pt (sample L7N-164).

Walk south along the road for about 150 m to north end of large stripped outcrop ridge. Start by the rusty weathering part of outcrop closest to the road.

STOP 9C. ROAD ZONE

The Road zone exposes several different rock types of the River Valley intrusion, including massive gabbroic anorthosite and gabbro that "overlie" the inclusion-bearing and breccia units. A large, faulted felsic dike cuts the breccia zone and appears to originate from the footwall contact that is exposed toward the north end of the clearing. This area is one of the original discovery zones from the fall of 1998, with the remnants of the original exposed pit located at the extreme northeast corner of the clearing, alongside the road. Another cleared area, referred to as the Road zone east, is located immediately east of the road. The highest assay value from samples collected in this area is 13.4 g/t Au+Pd+Pt (sample RZ-361).

Follow the ATV trail situated on the east side of the road by the Road zone and walk southeast. On the way you will pass by North zones 1, 2 and 3 on your left. After about 200 m (about grid line 3+00N), follow a drill road north (toward the left) for about 100 m (near diamond-drill hole collar RV00-05). The Central zone is located on a north-trending outcrop ridge.

STOP 9D. CENTRAL ZONE

The Central zone exposes the inclusion-bearing unit (northwest part of clearing) (Photo 13b, 13d) and the mafic breccia unit (southeast part of clearing). Note the large fragments in the outcrop at the northeast edge of the clearing and note the leucocratic nature of the matrix (*see* Photo 13b) for comparison to the melanocratic matrix you will see in the South zone (*see* Photo 13c). The highest assay value for samples collected from this zone is 9.1 g/t Au+Pd+Pt+Rh (sample CZ-54).

Retrace your route back to the ATV trail and continue south for roughly 250 m.

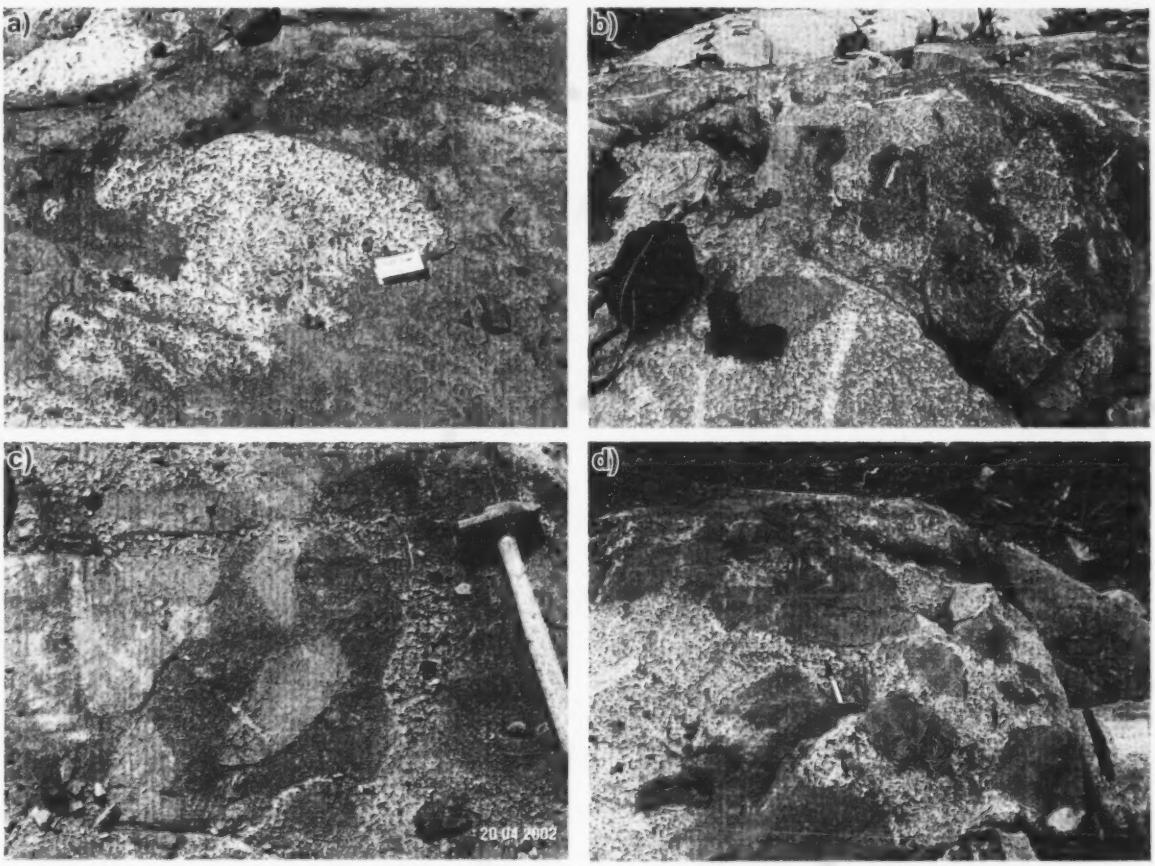

Photo 13. Photographs illustrating the textural variation observed in the Inclusion-Bearing unit in the Dana North area (Day 3, Stop 9). **a)** Large, leucogabbronorite fragment hosted in a gabbronorite to pyroxenite matrix. Scale card is approximately 8.5 cm long. **b)** Gabbronorite to pyroxenite fragments hosted in a leucogabbronorite matrix in stripped outcrop at the central zone (stop 9D, Day 3). **c)** Mafic fragment and matrix-dominated portion of the Inclusion-Bearing unit at Dana South (stop 9F, Day 3). Hammer handle is approximately 35 cm long. **d)** Gabbronorite to pyroxenite fragments hosted in a leucogabbronorite matrix in stripped outcrop at the Central zone (stop 9D, Day 3). Marker is approximately 14 cm long.

STOP 9E. TRENCH ZONE

The Trench zone is one of the original discovery areas from the fall of 1998, with one of the original trenches (circa 1969) still visible along the west edge of the clearing. This zone exposes the mafic breccia unit, which is best developed along the western edge of the clearing (Photo 13c). Note the "shotgun-pattern" of sulphide mineralization "bleeding" in outcrop. A plagioclase-phyric dike (Matachewan swarm?) occurs in the sheared contact with footwall migmatitic paragneiss (altered Pardo gneiss) and is in sharp contact with rocks of the intrusion along the southern edge of the clearing. Samples from the dike have analyzed up to 818 ppb Au+Pd+Pt+Rh and 448 ppm Cu (sample TZ-03); finely disseminated sulphide mineralization is visible. Take time to look at the "fault breccia" located at the east edge of the clearing, just north of the dike. What is this breccia reminiscent of? The highest assay value from samples collected from this zone is 13.2 g/t Au+Pd+Pt+Rh (sample TZ-07).

Keep walking south along the trail down the hill from the Trench zone and cross the stream (beaver dam) that connects Platadium Pond on the right with Dana Lake on the left. A worn bush trail will take you to the South zone clearing. Total distance from the Road zone to the South zone is about 650 m.

STOP 9F. SOUTH ZONE

The South zone is one of the original discovery areas from the fall of 1998. Initially, several small pits along the eastern and northwestern edges of the clearing were the only exposed areas of mineralized outcrop. It is in this area that one grab sample assayed greater than 12 g/t Au+Pd+Pt. This clearing exposes the mafic mineralized breccia unit along the east half of the outcrop and the Inclusion-Bearing zone along the western half. Note the presence of several northeast-trending diabase dikes that cut across stratigraphy. The highest assay value to date from samples collected in this area is 16.4 g/t Au+Pd+Pt+Rh (sample SZ-219). Note the presence of blue-grey quartz grains in the mafic rocks and its general association with sulphide mineralization, particularly in the area of the large blast pit.

This ends Day 3. Return to vehicles and retrace route to Highway 805, head south on Highway 805 to River Valley, Warren and Highway 17.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.